Small Cells 2019

Abstract: This report provides a comprehensive analysis of trends in Small Cell development, including 2G, 3G, 4G, and 5G. The report covers both indoor and outdoor units in many variations including integrated, RRH, and distributed DRS units. The report covers residential, enterprise, and carrier segments, and provide a forecast of 5G small cells deployed in sub-6GHz bands. The report includes shipment, revenue, pricing, and market share data.

Kyung Mun

April 2019

MOBILE EXPERTS

Small Cells 2019

TABLE OF CONTENTS

CHARTS

FIGURES

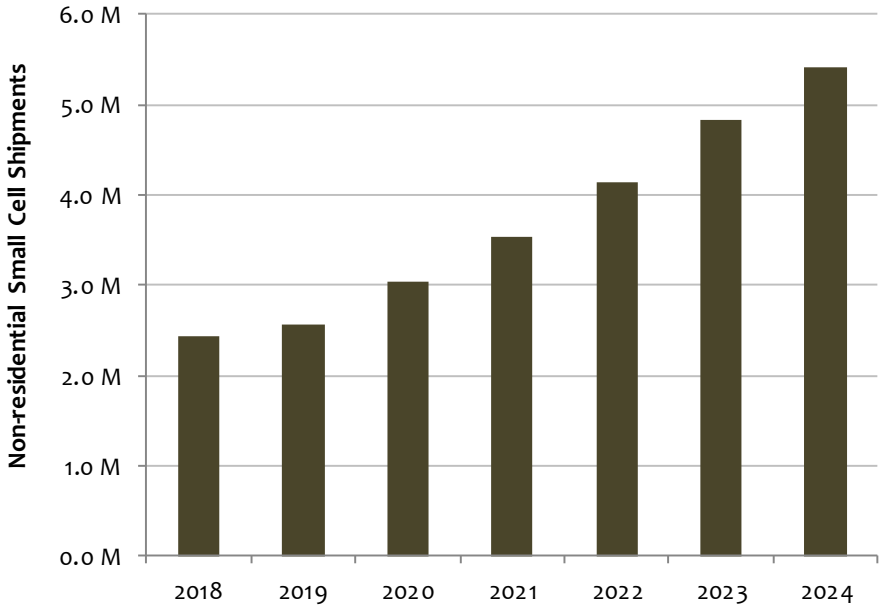
MOBILE EXPERTS

SMALL CELLS 2019

MEXP-SMALLCELLS-19
April 2019

1 EXECUTIVE SUMMARY

As expected, the Small Cells market experienced strong growth in 2018. Unit shipments grew 20% year over year to just under 4M units in 2018 with strong indoor small cell deployments in China, North America, and APAC fueling the growth. The revenue also grew 20% year over year to reaching $2.9B in 2018. Excluding residential femtocells, which represent almost 40% of all small cell units shipped but only 5% of market revenue opportunity in 2018, the Small Cells market grew over 40% year over year in unit volume.



Source: Mobile Experts

Chart 1: Non-Residential Small Cell Growth Forecast

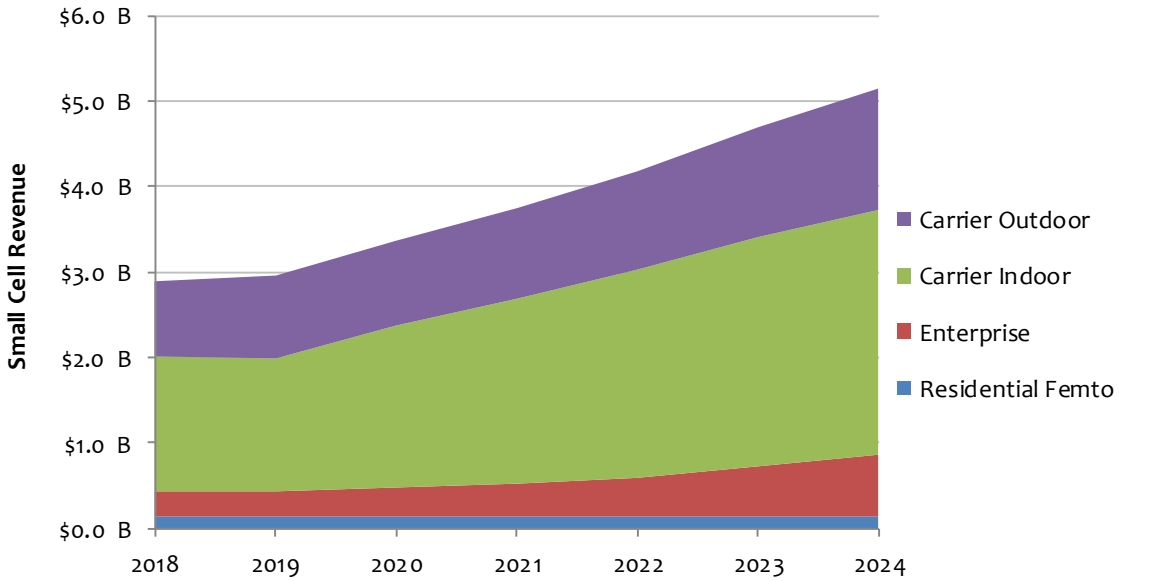
The residential femtocell market continues to be pretty steady with regional differences in the outlook. In developed markets, we see steady adoption of LTE-only femtocells. Meanwhile, in India, the market competition is driving demand for small cell solutions to augment capacity. Over the long run, we see a fairly flat growth outlook with only 1% CAGR growth from 2018 to 2024.

In the Enterprise segment, we expect a flat outlook for the next couple of years as developed markets transition to 5G. After that, we forecast stronger growth from CBRS activities in the USA and global enterprise adoption of Private LTE and 5G applications in the 2021-2022 time frame -- as industrial automation drive the need for deterministic, low-latency aspects of LTE and 5G small cells.

The Carrier Indoor segment, which includes the Distributed Radio Systems (DRS) such as Huawei Lampsite, Ericsson RadioDot, ZTE Qcell, and Nokia ASiR, will remain a key driver for the overall market. 5G network transitions will require indoor small cell deployments to

handle the majority of capacity handling and use cases. Providing good user experience, especially at higher bands, requires seamless coverage indoors as traditional "outside-in" coverage from macro sites will be even more challenged at the higher 3.5 GHz and millimeter wave bands. Mobile Experts forecasts the Carrier Indoor small cells to grow at 15% CAGR from 2018 to 2020.

In the Carrier Outdoor segment, we see some headwinds particularly in China, Korea, and Japan where macro grids are pretty dense. We believe that 5G Massive MIMO at the C-band can provide enough network capacity to not warrant small cell densification. Despite the challenges, small cell densification will be needed in North America and parts of Europe where site densification is nowhere near the level in China, Korea, and Japan. Moreover, Private LTE and 5G applications will drive some outdoor small cell deployments at factories, ports, and other key industrial facilities. Over the long run, the Carrier Outdoor small cells is expected to grow at 7% CAGR.



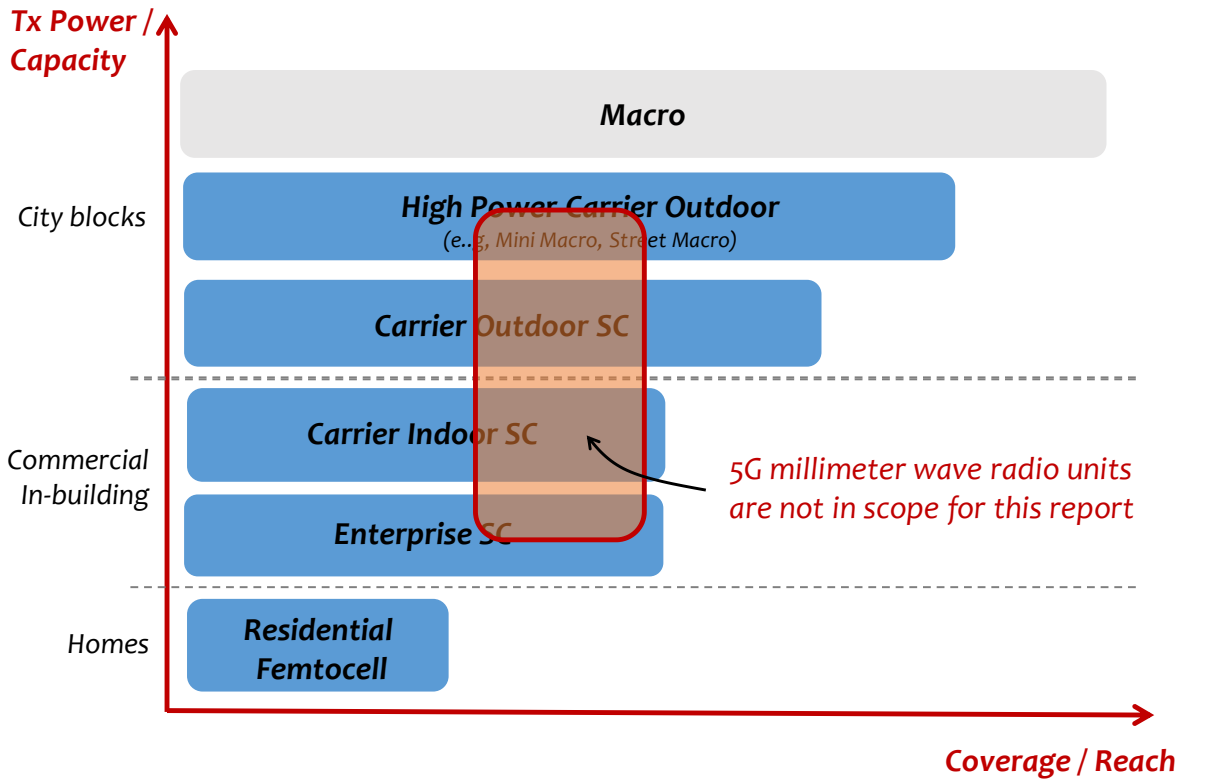
Source: Mobile Experts

Chart 2: Small Cell Revenue Forecast, 2018-2024

As the market transitions to 5G, we see some challenges in the Small Cells market especially in the outdoor segment. Overall, however, we see growth drivers in Private LTE and 5G, which is included in this forecast, especially as enterprises adopt LTE and 5G infrastructure solutions to help in their industrial automation drive in a big way. Even after excluding the 5G millimeter wave radio units, our Small Cells market is expected to grow from over $2.9B in 2018 to $5.2B in 2024 – a 10% CAGR – not explosive, but not too bad either. It is becoming a stable part of the overall RAN market.

2 PREFACE

Our *Small Cells* market study has been tracking the industry for many years, and we have generally categorized Small Cells by RF transmission power. In our past study, the highest power sub-6GHz small cell device is we call "Hi-Power Carrier Outdoor" with up to 40W composite power as highlighted below. For the millimeter wave case, we had set an arbitrary designation of anything below +52 dBm as a "5G millimeter wave small cell." So, anything above that is considered a Macro and covered in our *Macro Transceiver* study.



Source: Mobile Experts

Figure 1. Small Cell Definitions and Scope

Besides the RF transmission power, we realize that a Small Cell can be defined by size (form factor), coverage area, or use case (indoor vs. outdoor). With 5G radios operating in the millimeter wave, it is difficult to simply apply the "output power" filter to designate whether a 5G millimeter wave radio is a small cell or not. For example, many 5G millimeter wave radio units at MWC 2019 were fairly small (~400 x 200 x 200 mm) enough to mount on poles but most were capable of emitting much higher EIRP but have limited coverage area due to the millimeter wave propagation.

Over the past year, we have noted that many vendors were introducing 5G millimeter wave radio products with higher effective radiated output power (around +55 dBm) as a

"small cell." To simplify and keep things streamlined between our Macro Transceiver and Small Cells research studies, we have decided to follow the *5G Millimeter Wave* radio infrastructure products in a separate report. Hence, this report should more specifically be called "Sub-6GHz Small Cells" report, but we won't do that. Instead, we have adjusted our market forecasts to exclude the 5G millimeter wave radio units.

3 MARKET ENVIRONMENT

The market activity across both indoor and outdoor deployments is strong. As the mobile networks get denser, siting challenges are bringing about new small cell architectures like wireless relay and strand mount for example. Beyond the licensed spectrum, the use of shared and unlicensed spectrum via CBRS and LAA is opening new market opportunities like neutral host in-building wireless, MVNO offload, and fixed wireless access to name a few.

The industry transition to 5G is providing a tailwind in the near term as regulatory agencies are more eager to open up more spectrum. CBRS and other new bands appear poised to help ease infrastructure challenges. The new spectrum availability in high bands and flexible licensing rules around CBRS, in particular, are bringing new players and new business opportunities for the small cell product and wireless infrastructure vendors.

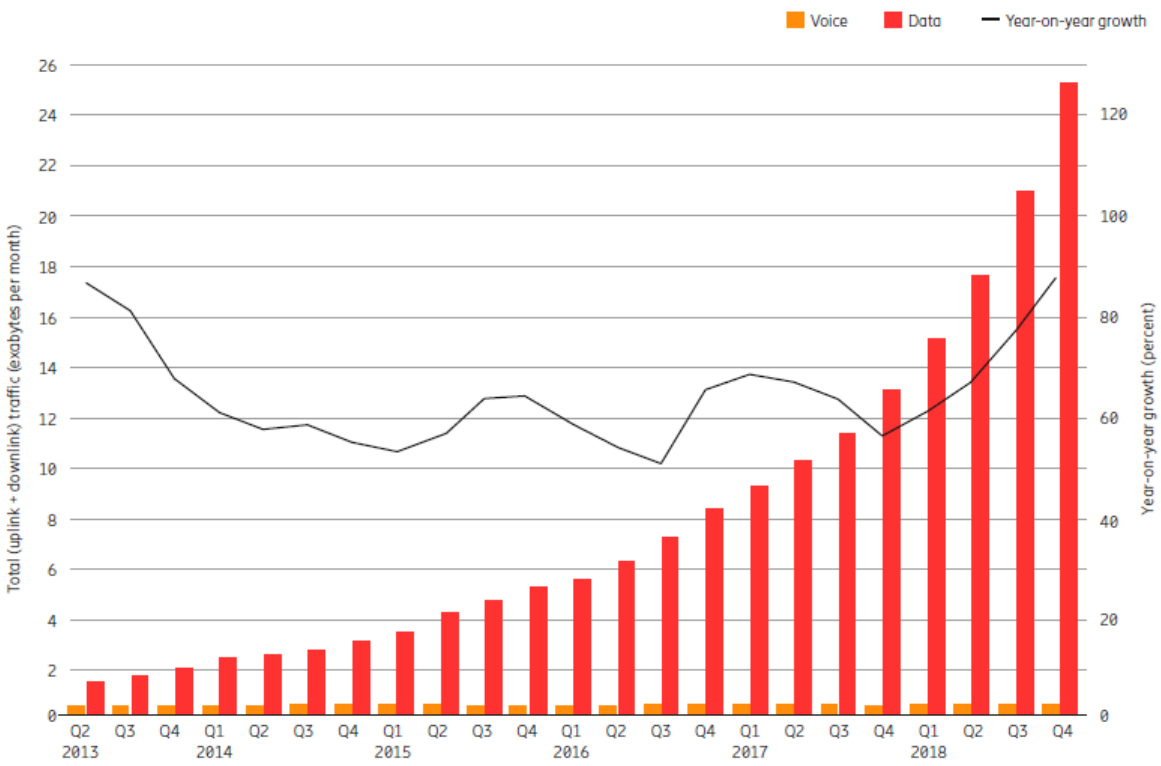
Demand Drivers Haven't Changed

The mobile traffic continues to grow. According to Ericsson's latest Mobility Report, the global monthly mobile data traffic grew over 80% year over year, which was driven largely by increased traffic in China. While this pace of growth is not the same everywhere, the growing trend in the 50% range has been observed in many developed markets. Consumers love their smartphones! Of course, the flip side of this explosive growth is that operators are continuously upping their network capacity to keep pace with the growing demand.

Fundamentally, operators have three key levers to "manufacture" more capacity:

- Add more cell sites (densification)
- Add more carriers (more spectrum)
- Gain spectral efficiency through better technology (more "bits per Hz")

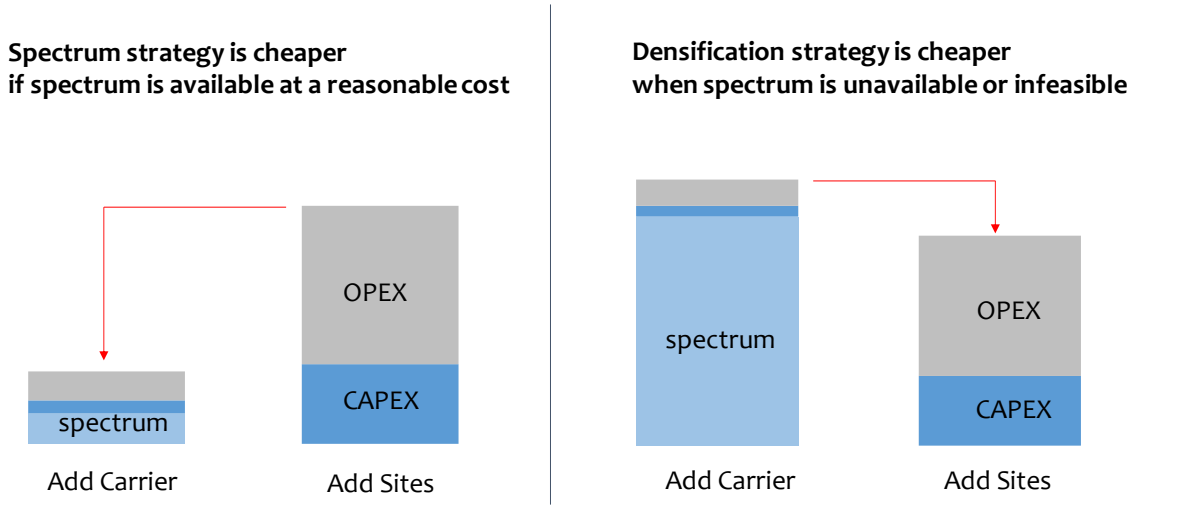
Out of the three, operator investment decisions really fall to the first two. Leveraging the latest technology, from LTE to 5G, for instance, has become a regular routine in the industry. A decision to choosing the "densification vs. spectrum" depends on CAPEX and OPEX cost considerations of adding more spectrum on existing RAN infrastructure vs. adding more sites through small cells for instance.



Source: Ericsson Mobility Report, 4Q18

Figure 2. Mobile Traffic Growth Continues to Accelerate

Generally, it is cheaper to add spectrum, assuming that an operator has spare spectrum available in a given market. The operator can add additional frequency carriers via software upgrade on existing RAN sites without incurring expensive OPEX costs such as site lease, backhaul, maintenance, etc. However, in certain cases where spectrum cost is too high or spare spectrum is not available, operators are forced to densify to increase network capacity. For example, back in 2015 when AWS-3 spectrum was auctioned in the USA, the spectrum cost ballooned to historically high levels where the average paired AWS-3 spectrum went for as much as $2.70 per MHz/Pop to a tier 1 operator. In top metro markets like NY and LA, the operators paid double that amount. In these extreme cases, it is better to densify the market with small cells in key traffic hotspots rather than adding that expensive spectrum.

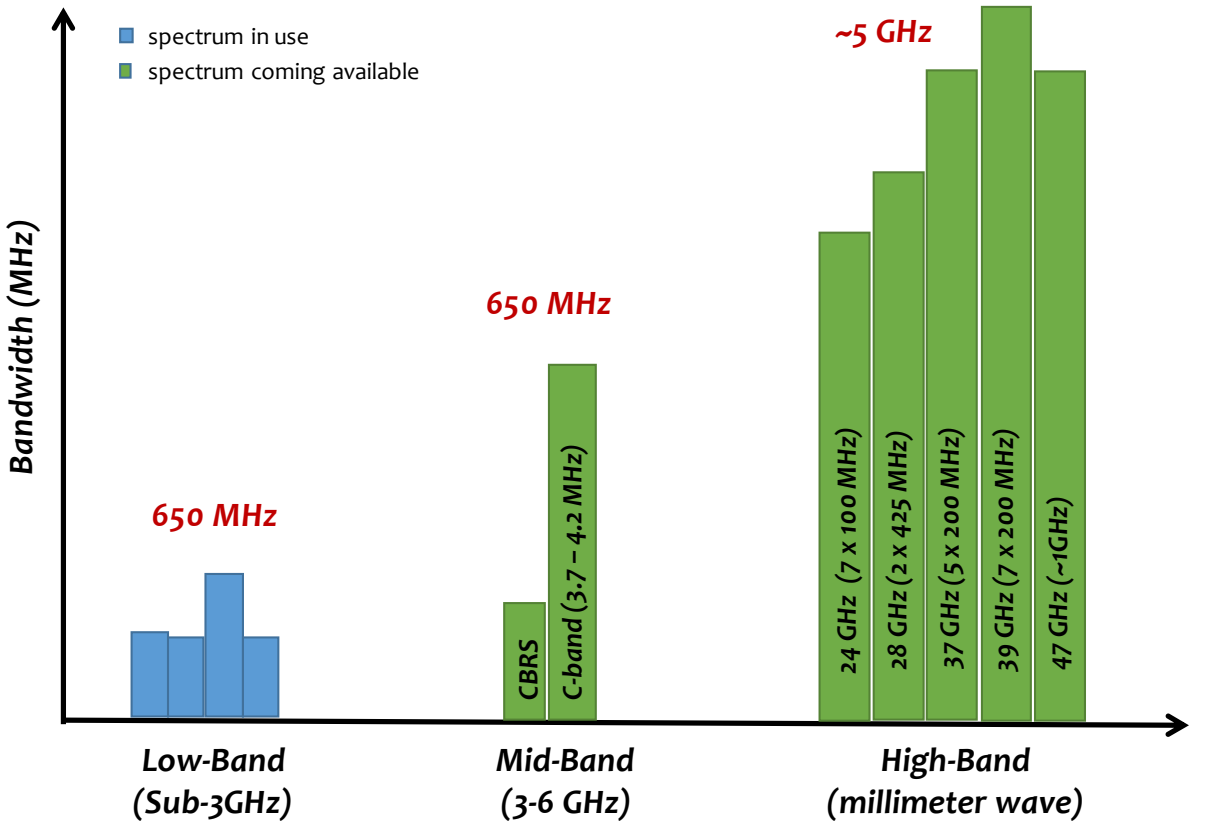


Source: Mobile Experts

Figure 3. Spectrum vs. Densification Tradeoff in Capacity Strategy

…But the "Spectrum vs. Densification" Investment Tradeoff Has Changed

As operators consider their next move in network capacity strategy, the future looks bright in terms of the amount of spectrum coming available, but the spectrum coming available are higher frequency bands. Even though each operator will likely have ~100MHz of C-band spectrum and possibly 10x that amount in the higher millimeter wave band, these higher bands have limited RF propagation such that operators have to deploy radio sites closer, in order to keep mobile coverage in line with what consumers are used to in today's LTE networks. At higher bands, operators probably won't have the choice of simply adding carriers onto existing RAN infrastructure especially the North American operators whose macro networks are less dense. They need to add more cell sites, and many of these will be small cell sites especially at the millimeter wave bands.



Source: Mobile Experts

Figure 4. ~10x More Spectrum Coming Available in the USA

Spectrum Abundance in C-band, Millimeter Wave, and More

Beyond the core 1-2 GHz spectrum for Macro network services, small cell deployment in the sub-3 GHz has been prevalent in the past years as operators densify their LTE networks. As the 5G commercialization ramps up, regulators are opening up more spectrum – whether they are licensed, unlicensed, or shared. Below is a summary list of new spectrum that is coming available.

Spectrum	Duplex Mode	Bandwidth	Channel Bandwidth	Access Technology
3300 – 3800 MHz	**TDD**	**500 MHz**	**5..20 MHz**	**5G NR**
3450 – 3550 MHz (US)	TDD	100 MHz	?	? (possibly CBRS)
3550 - 3700 MHz (US)	TDD	150 MHz	10 MHz	CBRS
3300 – 4200 MHz	**TDD**	**900 MHz**	**10..100 MHz**	**5G NR**
3700 – 4200 MHz (US)	TDD	500 MHz	?	?
4400 – 5000 MHz	**TDD**	**600 MHz**	**40..100 MHz**	**5G NR**
5150 – 5850 MHz	**TDD**	**~650 MHz**	**20..160 MHz**	**Wi-Fi / LAA / MulteFire**
24.25 – 27.5 GHz	**TDD**	**3250 MHz**	100 MHz (estimate)	**5G NR**
24.75 – 27.5 GHz (China)	TDD	2750 MHz	100 MHz (estimate)	5G NR
24.25 – 27.5 GHz (EU)	TDD	3250 MHz	100 MHz (estimate)	5G NR
26.5 – 29.5 GHz (under consideration)	**TDD**	**3000 MHz**	100 MHz (estimate)	**5G NR**
27.5 – 28.35 GHz (USA)	TDD	850 MHz	100 MHz (estimate)	5G NR
26.5 – 29.5 GHz (Korea)	TDD	3000 MHz	100 MHz (estimate)	5G NR
27.5 – 29.5 GHz (Japan)	TDD	2000 MHz	100 MHz (estimate)	5G NR
37 – 40 GHz (under consideration)	**TDD**	**3000 MHz**	100 MHz (estimate)	**5G NR**
37 – 42 GHz (USA)	TDD	5000 MHz	100 MHz (estimate)	5G NR
37 – 42.5 GHz (China)	TDD	5500 MHz	100 MHz (estimate)	5G NR
40.5 – 43.5 GHz (EU)	TDD	3000 MHz	100 MHz (estimate)	5G NR

Source: 3GPP, Mobile Experts

Note: GREEN – licensed spectrum (or likely); YELLOW – shared spectrum; BLUE – unlicensed spectrum

Figure 5. New Spectrum for Macro and Small Cells

The new spectrum available for small cell deployments can be grouped into three band ranges:

1. 3 GHz "C-band" (including the 3.5 GHz CBRS shared band)
2. 5-6 GHz unlicensed band (LAA and 5G NR Spectrum Sharing)
3. 27-40 GHz millimeter wave band

New spectrum for 5G deployment offers vendor opportunities across a wide variety of RAN products ranging from Macros to Small Cells. For example, in the USA alone, about 10x more spectrum will come available for operators and enterprises alike. While we expect most operator macro deployments to center around Massive MIMO on the C-band spectrum to minimize the need for outdoor small cells (for 5G), we see strong growth

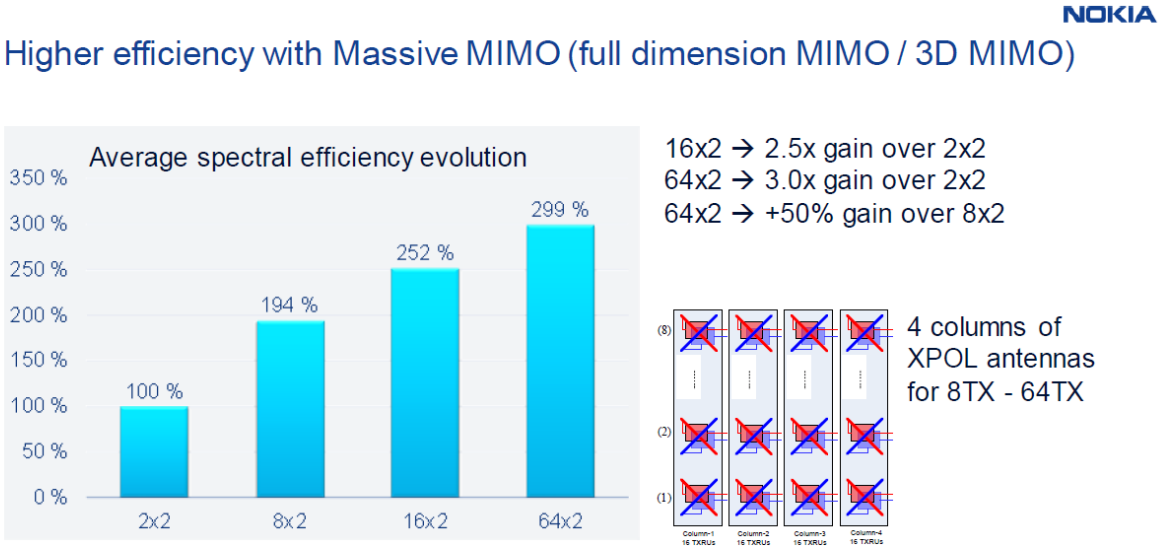
opportunity in Carrier Indoor small cells. For 5G networks centered around the millimeter wave spectrum deployment, we see strong growth for high power 5G millimeter wave radios -- small in size, but with high transmission output power -- in key urban areas. Meanwhile, we see integrated 5G millimeter wave small cell products being deployed in key public venues like stadiums and arenas.

Small Cell Implications in 5G Transitions

LTE has been a boon for the Small Cells industry. The high utilization of LTE networks worldwide has forced operators to densify their networks with small cells. As the leading markets in North America, APAC, and China now transition to 5G, those transitions will surely bring new market drivers to how the operators will utilize small cells in their overall goals to expand network capacity and user experiences. The spectrum choice and use cases will be huge factors in this, and regional differences will be reflected in the future outlook for the Small Cells industry in respective regions.

Role of Carrier Outdoor Small Cells in 5G Massive MIMO Networks

Massive MIMO will be one of the key technology pillars behind 5G networks. Operators are expected to get 2-3x network capacity gains through higher spectral efficiency. Moreover, massive MIMO improves coverage with active antenna gains. With downlink and uplink de-coupling in 5G NSA operation whereby control signaling is anchoring on LTE channels, mobile coverage can be further extended. By deploying 5G in the C-band with Massive MIMO, operators can largely utilize current macro sites to provide similar 5G mobile coverage footprint especially in China, Korea, and Japan where the operators there have macro site grids that are much denser than in North America. Therefore, it is no surprise that operators there are eager to deploy 5G in the C-band, with Massive MIMO, to take advantage of large channel bandwidths (~100 MHz) in the C-band without having to densify their macro layer further.



Source: Nokia (Amitava Ghosh), IEEE 5G Summit 2017

Figure 6. Massive MIMO provides higher efficiency gains

In denser markets in China, Korea, and Japan, 5G deployments in the C-band with Massive MIMO will lessen the need for Carrier Outdoor small cells since the operators there can more broadly expand network capacity through C-band spectrum without small cell densification. Instead, they will likely focus their efforts on indoor small cell deployments at key venues to extend the 5G C-band coverage indoors where most of the mobile consumption happens.

In North America, 5G deployments will be much more diverse across the different spectrum bands. For AT&T and Verizon, the initial 5G deployments will largely center around the millimeter wave spectrum since the C-band spectrum hasn't been allocated yet. While the 3.5GHz CBRS band offers some pathway for 5G "C-band" deployment using Massive MIMO, it is a bit more complicated with the shared spectrum regime in the band, and the available spectrum blocks will be skinny Hence, we believe they will be more focused on 5G millimeter wave deployments for fixed wireless and more nomadic mobile access situations in hotspot locations in urban areas while they await for the 3.7 -4.2 GHz spectrum ruling to be worked out. Here, we expect the Carrier Outdoor small cell market to continue its growth as a broad array of mobile operators, cable players, WISPs, and enterprises to take advantage of the maturing CBRS ecosystem.

Generally, we believe the "5G C-band" markets including China, Korea, and Japan will focus heavily towards 5G Massive MIMO deployments outdoors to expand capacity and focus more towards indoor small cell deployments while the "5G millimeter wave" market in North America to see a robust growth in Carrier Outdoor small cell deployments in the near term. In the long run, we expect the Carrier Outdoor small cell segment to be boosted by enterprise adoption of Private LTE and 5G applications.

What's a 5G Residential Femtocell?

In LTE, the role of Residential Femtocells is clear. The femtocells provide coverage and capacity enhancement for subscribers at their SOHO/homes. It is a good solution to keep subscribers happy and reduce churn. Operators can justify spending on these inexpensive devices as a "churn reducer." In 5G, especially in markets where millimeter wave spectrum is the primary frequency band for initial 5G services, operators may need to put femtocells at every home since the propagation will be limited (relative to sub-3GHz carriers).

Source: Movandi

Figure 7. Millimeter Wave Signal Booster (Movandi BeamXR)

In 5G millimeter wave implementations, coverage extension, especially inside building and homes, may be more important than providing capacity augmentation through traditional femtocell solutions that handled baseband processing and radio transmission. Some vendors are starting to address this challenge by introducing 5G millimeter wave "extenders" like the one shown in the figure above. Movandi launched its BeamXR product at MWC 2019. While it is still very early in development, we believe the North

American operators are very motivated to extend 5G millimeter coverage more extensively and economically in the next couple of years, and we may see more "signal booster" products like the above instead of traditional femtocells with baseband processing embedded for 5G.

Small Cells in Rural Markets

Small cells have become viable rural coverage solution in many markets as agile vendors have been introducing innovative compact solutions to meet many challenges of deploying RAN infrastructure in rural areas. Companies like Parallel Wireless, Airspan, and others are introducing complete solutions that include multiple backhaul options including satellite, wireline, and LTE relay for simple installations. For instance, Airspan's recent acquisition of Mimosa brings additional backhaul solutions for the company's standalone wireless backhaul solutions as well as integrated wireless relay small cell solutions.

Most importantly, the small cell specialists like Airspan and Parallel Wireless bring much lower priced compact RAN solutions that can bring focused coverage and capacity solutions in rural markets where they are needed most. Rural carriers can ill-afford to use traditional macro base station deployment models that have significantly higher CAPEX and OPEX models than Hi-Power Carrier Outdoor small cells in the marketplace. Deploying lower-priced small cells in select locations where the subscribers are is much more economical for the price-sensitive rural carriers. Moreover, the compact design and form factors provide greater optionality for the rural carriers to deploy small cell networks on non-traditional site locations besides traditional macro towers.

Small Cells in Private LTE/5G Markets

The innovative small cell products that offer multiple siting and fronthaul/backhaul options are expanding the market opportunity beyond Tier 1 and smaller operators, and into industrial enterprise segments. With expanding opportunities across a wider swath of licensed and unlicensed spectrum bands ranging from low sub-3GHz to the millimeter wave spectrum, the Private LTE/5G ecosystem is coming together just as several large industry verticals like Mining and Manufacturing are seeking new connectivity options that can handle complex industrial automation in challenging environments.

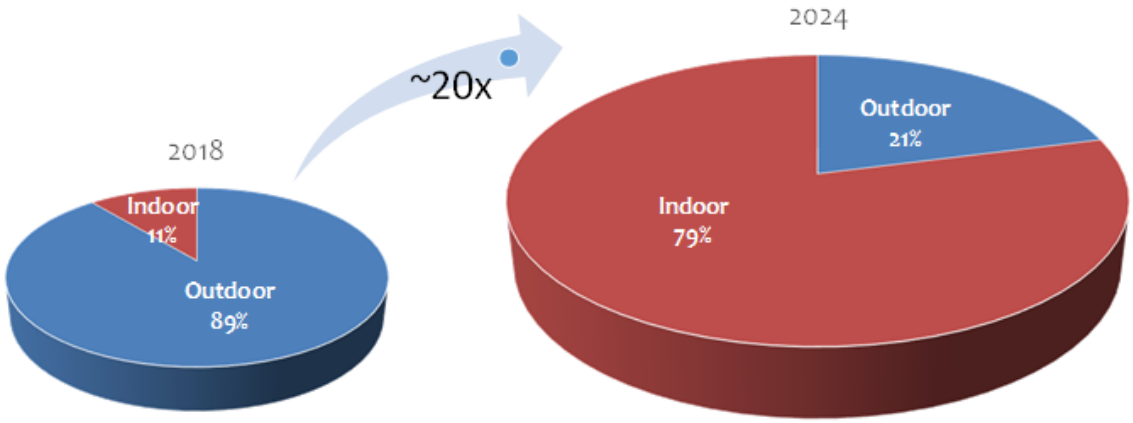
Here are the major industry sectors where we see Private LTE and 5G adoption taking place and will drive further small cell growth in the coming years:

- Oil & Gas
- Mining
- Water and Electric Utilities
- Transportation (Airports, Shipping Ports, and Railways)
- Public Safety and Military
- Manufacturing (Smart Factories)

Source: ABB, MIT Technology Review, WikiMedia

Figure 8. Automation Is Driving Private LTE and 5G Adoption in Many Industries

While the current demand resides mostly in higher-power outdoor small cells, we expect the share of indoor small cells will increase dramatically as several large manufacturers start Private LTE/5G implementations to automate their factories.[1] In the meantime, the growth of small cell shipments for the Private LTE and 5G increase almost 20 fold in the next six years. In some countries like Germany, regulators are even allocating designated spectrum just for industrial use.



Source: Mobile Experts

Figure 9. Small Cell Shift from Outdoor to Indoor in Private LTE and 5G applications

[1] Mobile Experts' *Private LTE and 5G 2019* market study, February 2019

Regulatory Update – Changes and Challenges

With 5G commercialization ramps up in the USA, Korea, and China, the regulatory environment has become more dynamic. Vendors and operators are pushing to have more spectrum wherever they can find them. Most of the 5G spectrum story has centered around the 3.5 GHz C-band and the millimeter wave band around 27-40 GHz. In addition to spectrum, the Federal Communications Commission (FCC) in the USA, in particular, has been active in promoting site rule changes to expedite cellular infrastructure siting. In the current political climate with trade wars and government scrutiny around technology mergers and IPR rights, the "5G" race has taken on a national significance. In this environment, regulators don't want to be seen as an inhibitor to the national interest of achieving global first in 5G network launch.

More Spectrum

Regulators around the globe are actively working to open up hundreds of MHz of the C-band and thousands of MHz in the millimeter wave band. The global harmonization of 5G spectrum around the 3.5 GHz C-band is happening. Each national and regional regulators are working towards opening up wider channel bandwidth in the "mid" band below 6 GHz and the millimeter wave bands above 20 GHz:

- Japan: The Japanese Ministry of Internal Affairs and Communications (MIC) is considering the 3600-4200 MHz, 4400-4900 MHz, and the 27-29.5 GHz bands for 5G and plans to assign spectrum in the first half of 2019. MIC may also consider the 3400-3600 MHz band as well.
- Korea: South Korea has completed its 5G spectrum auction in 2018 for both the C-band (3.42 – 3.7 GHz) and the millimeter wave band (26.5 – 28.9 GHz).
- China: The Ministry of Industry and Information Technology (MIIT) has set aside the 3300-3600 MHz and 4800-5000 MHz bands for 5G. Rumors indicate that China Mobile is likely to get the 4800-5000 MHz block, while China Unicom and China Telecom are likely to get spectrum in the 3300-3600 MHz band as well as authorization to use the 700 MHz or other 900 MHz-2.5 GHz spectrum for 5G NR. The 24.75-27.5 GHz band and 37-43.5 GHz bands are also under consideration by the MIIT for 5G trials.
- Europe: Several countries have already auctioned 5G spectrum around the 3.4-3.8 GHz band including Finland, Ireland, Italy, Spain, and the UK and many are in the queue to complete spectrum auctions in the next couple of years. Also, European regulators have designated a "pioneer band" at 24.25 – 27.5 GHz as a 5G band, and another likely band at 40.5-43.5 GHz.
- United States: The bands between 3.3-3.5 GHz and 3.7-4.2 GHz are possibilities for 5G allocation, but are also heavily sought by other stakeholders. The Federal

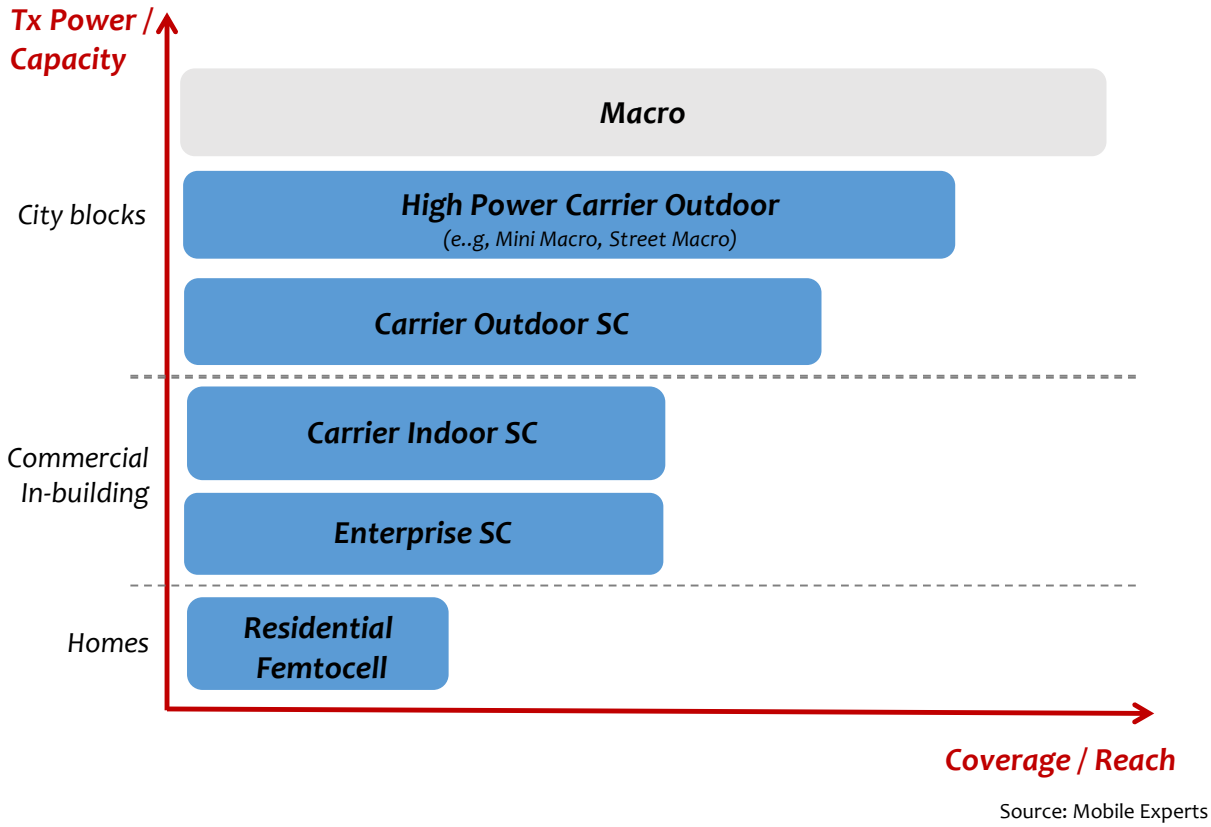
Communications Commission is active in the millimeter wave spectrum auction, and several other spectrum bands are in the queue for auction or rulemaking including the 3.7-4.2 GHz band and the PAL auction of the CBRS band in the 3.55-3.7 GHz.

Small Cell Siting

In addition to making available more spectrum, regulators have been looking to streamline the wireless infrastructure siting approval process. Unlike in China where telecom infrastructure rulemaking is more centralized and streamlined, infrastructure regulatory procedures can be excruciatingly slow in North America and in Europe where infrastructure approvals are conducted at the local level. A mobile operator in the USA looking to deploy thousands of small cells in a market will need to deal with the individual municipalities. Timely access to siting for small cell deployments have become an important issue for the industry. While the FCC continues to streamline the siting process at the national level, operators and infrastructure suppliers still have to work closely with local city agencies today. Verizon's Smart City initiatives with several large cities for 5G services and trials is a good model for both the wireless industry and municipalities.

4 TECHNOLOGY BACKGROUND

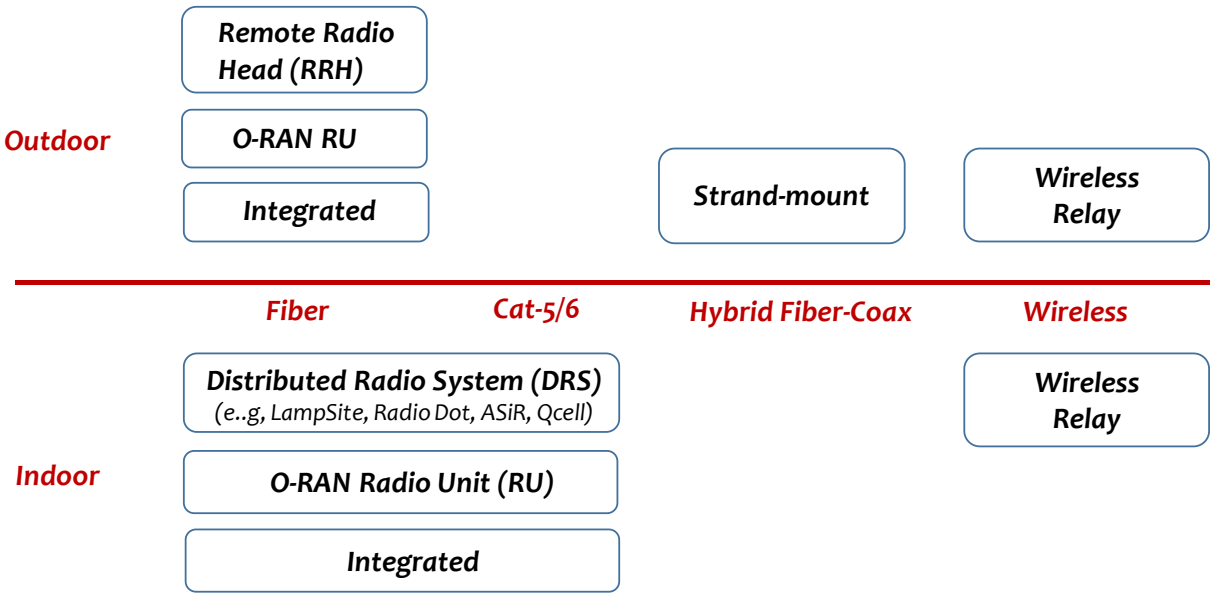
At a high level, small cells offer low-cost RAN options for carriers and enterprises alike to fit different needs. While there are many ways to define what a small cell is, Mobile Experts defines a small cell by RF transmission power (and implicitly subscriber capacity) and whether it is deployed indoors or outdoors. As shown below, we typically define any mobile radio units that emit below 40W composite of transmission power. For example, a "Mini Macro" LTE radio that can transmit at 2x20W (20W per antenna) is considered a small cell in our definition – more specifically a *High Power Carrier Outdoor* small cell. A *Carrier Outdoor* small cell typically transmit at 5W per antenna. For indoor small cells, we segment based on whether operators/carriers deploy the radio units by who actually purchases or manages the radio units (*Carrier Indoor* vs. *Enterprise*). We further define very low-power (typically less than 50mW per antenna) *Residential Femtocell* for residential use.



Source: Mobile Experts

Figure 10. Small Cell Classification by Indoor vs. Outdoor

We further segment the small cell types by the fronthaul/backhaul and siting options as shown below. The different small cell categories at the various scale of reach and capacity offer flexibility in deployment use cases.



Source: Mobile Experts

Figure 11. Small Cell Architectures by Backhaul/Siting Options

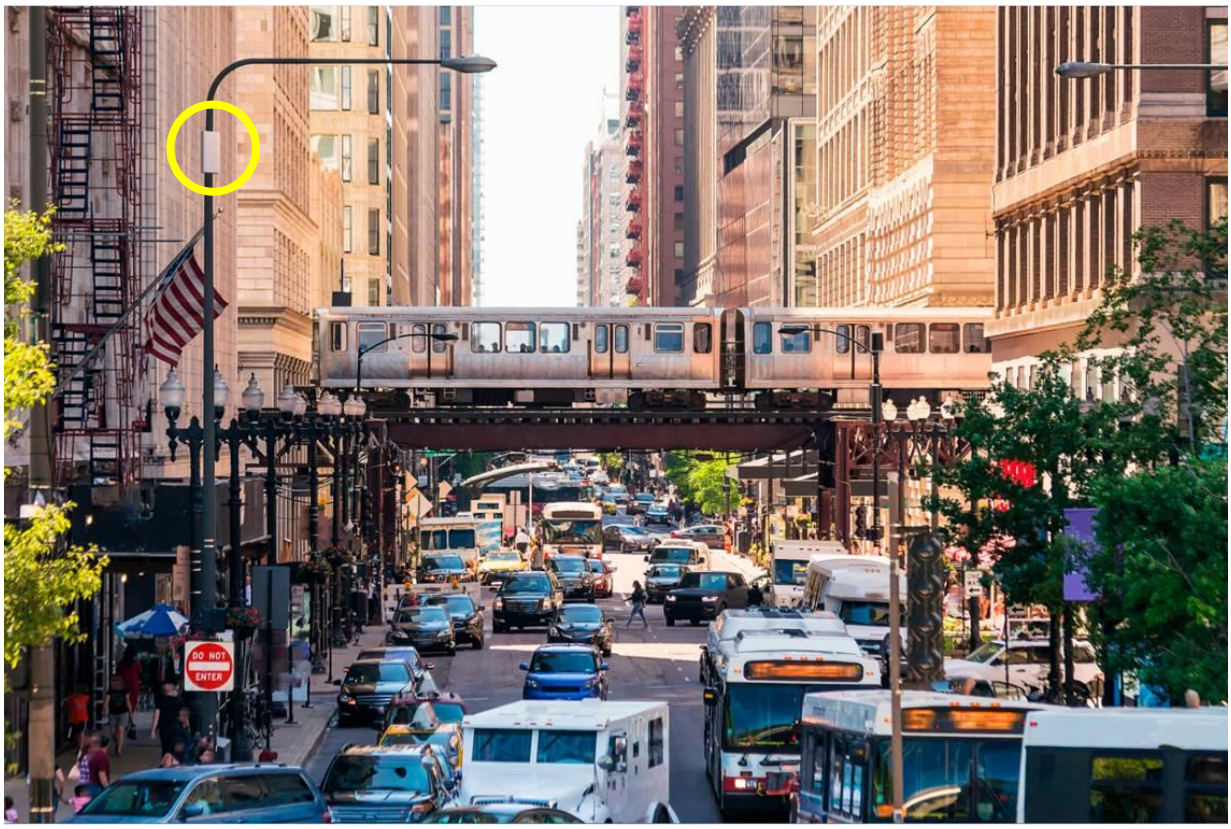
In fiber-rich regions such as China, Japan, and Korea, Remote Radio Heads (RRHs) are a popular option to extend macro coverage and capacity whereby radio units are connected to Macro baseband via fiber to extend the macro coverage. In places where backhaul options are limited, operators are known to deploy outdoor small cells on HFC strand-mount whereby power and backhaul are supplied through cable DOCSIS plants. In rare but extreme cases, some operators have leveraged LTE UE Relay mechanism to wirelessly backhaul LTE access traffic in situations where no adequate backhaul options are available. For indoor deployment scenarios, a "deeper" C-RAN architecture known as DRS (a term that Mobile Experts has coined to describe the architecture) has been widely adopted in China. Over the past year, tier 1 operators have been promoting the Open RAN (O-RAN) initiative to standardize the open interfaces between Distributed Unit (DU) and Radio Unit (RU) network elements. While O-RAN and DRS architectures are fundamentally the same, we distinguish the two as we believe market adoption and scale of deployments will differ. We generally view DRS as a "closed" version of O-RAN, or O-RAN as an "open" version of DRS -- or, at least, that's the operators' goal.

Outdoor Small Cells

Most major mobile networks are heterogeneous networks with layers of macrocells and small cells supporting multiple generations of 2G, 3G, and 4G. This layered network topology is a result of operators' push to provide seamless services across different generations of technology and client devices. As the mobile traffic demand continues to grow, operators are increasingly relying on both outdoor and indoor small cells to augment network capacity to alleviate the load on the macro layer and extend mobile coverage deep inside buildings where the macro signal is weak.

Hi-Power Carrier Outdoor – "Macro-Lite"

One of the key innovations of Small Cells is the fact that the radios are becoming small enough to place on street-level locations like light poles or side of a building. Flexibility to deploy elsewhere besides expensive macro towers is a huge boon to operators seeking radio infrastructure that can provide relatively big coverage and subscriber capacity in a small form factor. Nokia and some small cell specialists have found success with Hi-Power Carrier Outdoor Small Cells to meet this demand. These "macro-lite" small cells have been widely popular in filling weak coverage and performance areas where it's too costly and an "overkill" to deploy traditional macro base stations. With size dimensions around 300 mm (W) x 250 (H) x 150 (D), the Hi-Power Carrier Outdoor Small Cells have become popular "coverage and capacity" solution in many markets. While older-generation of Hi-Power Carrier Outdoor Small Cells offer 2x20W radios, we see newer versions that support 4T4R to extend capacity.



Source: Ericsson

Figure 12. Hi-Power Carrier Outdoor Installed on a Lamp in an Urban Environment

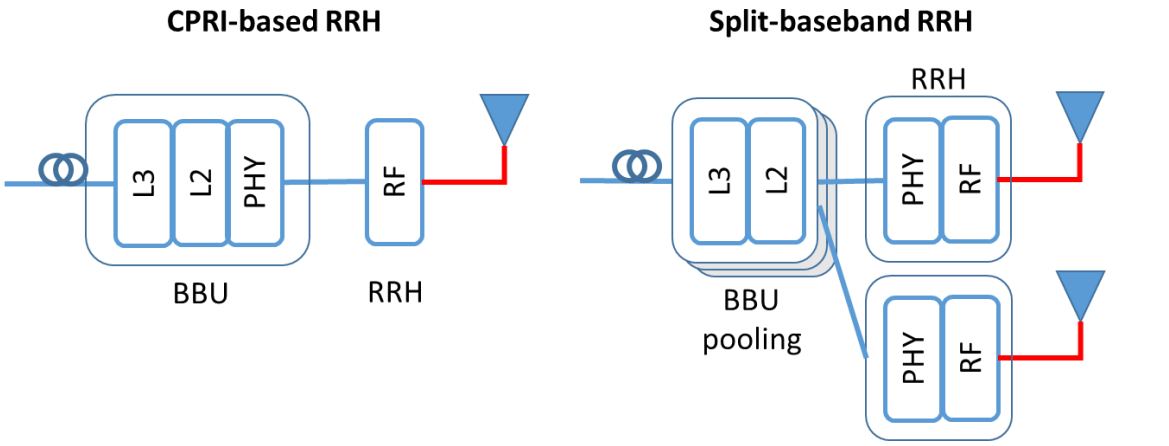
As the market transitions to 5G, some vendors are starting to introduce 5G baseband integrated, massive MIMO radios. For example, Ericsson's Street Macro 6701 falls in this

category. However, this product is for the millimeter wave spectrum since massive MIMO with high millimeter wave band makes it possible to fit in a relatively small form factor. For a sub-6GHz product, massive MIMO would probably only make sense in a macro base station form factor. This highlights the usefulness of this type of "street macro" radios that can provide macro-like capacity in a small form factor.

Remote Radio Head (RRH)

Macro networks can be extended, both indoors and outdoors, through the use of low power RRHs. For the past several years, we have forecasted RRHs using the CPRI or Split-baseband (other PHY/RF digital) interface as the defining characteristic of a Low power RRH (typically 5W per antenna).

1. CPRI-based RRH -- the fronthaul takes place at the PHY/RF interface in digital baseband data; and,
2. Split-baseband RRH -- a new interface point is defined, leaving some baseband processing in the radio unit and some in the centralized baseband processor



Source: Mobile Experts

Figure 13. CPRI vs. Split-baseband RRH Functional Overview

These units do not meet the strict definition of "small cells" since they do not contain all Layer 1-3 baseband processing. To be clear, we place units in the RRH category when they leave some portion of baseband processing to be done several miles away in a data center.

Wireless Relay Outdoor

Outdoor small cells with integrated wireless backhaul offer compact radio infrastructure solution in places where wireline backhaul option is not available. Small cell specialists like Airspan offer a host of outdoor small cells with multiple wireless backhaul options including LTE UE relay, 60GHz unlicensed, and even satellite. Even a major vendor like

Huawei offers a similar solution called Libero which contains integrated UE relay for backhaul. These "all-in-one" radio solutions are indispensable in challenging areas where wireline infrastructure is limited.

Source: Airspan

Figure 14. Wireless Relay Small Cells

Strand-Mount Small Cells

Like the Wireless Relay small cells, the Strand mount small cells offer quick time-to-market siting options for operators seeking to quickly deploy outdoor small cells. Obtaining siting approvals can be long and arduous in many markets in North America and Europe where local and regional approval procedures can take months, and the process can be different across each municipality. By working with cable operators who have a dense hybrid-fiber-coaxial (HFC) cable plant in the USA and other regions, obtaining small cell siting (on aerial cable strands) across multiple metro areas can be a matter of signing a commercial agreement with a few cable operators. Sprint's partnership with Altice (and Cox likely) is a good market indicator of this trend. Strand-mount small cells typically support both fiber and DOCSIS backhaul options.

Source: Mobile Experts

Figure 15. Samsung Strand-Mount Small Cell (from MWC 2019)

Indoor Small Cells

Carrier Indoor Small Cells provide a high-capacity solution for key public venues like transportation hubs such as airports, conference centers, malls, and other major indoor venues where RF coverage is lacking, or additional network capacity is needed. While DAS is a popular technology solution for multi-operator venues like large sporting stadiums, Carrier Indoor Small Cells offer a cost-effective solution when operators are making direct network investments which is common in the China and APAC regions. Here, the Distributed Radio System (DRS) such as Huawei's LampSite, Ericsson Radio Dot, and ZTE Qcell have been widely adopted by the Chinese operators. Last year, Nokia joined the group under the banner, "Digital Indoor System," to promote this architecture globally.

Over the past several years, Chinese operators have shown a clear preference for the DRS architecture. DRS has been used widely in large venue deployments such as airports, stadiums, airports, and malls where a combination of fiber and Cat5/6 cabling are used to distribute remote radio units through venues. With the 5G deployment in higher C-band, vendors will be bringing 4 x 250 mW radio units to provide equivalent RRU coverage in the lower LTE bands.

For smaller commercial spaces like small offices and retail shops, compact "all-in-one" Integrated Carrier Indoor small cells -- sometimes referred to as picocells -- offer a cost-effective coverage and capacity solution. While today's Carrier Indoor Small Cells typically support 2x250 mW output power, we expect to see 4T4R versions in the future as more devices that can take advantage of higher MIMO streams become more pervasive in the marketplace.

Residential Femtocells

The Residential small cell or femtocell has become a steady "workhorse" in operators' push to extend and expand LTE coverage. As LTE networks have matured and operators divert all services over the LTE network including voice (VoLTE), single-mode LTE femtocells are taking a greater share of today's shipment. While the total market opportunity is much smaller than high-performance carrier-grade small cells, the Residential Femtocells continue to offer a steady market opportunity for smaller RAN infrastructure vendors. This segment represents a proving ground for many small cell specialists who have moved onto selling higher margin carrier-grade small cells to tier 1 operator.

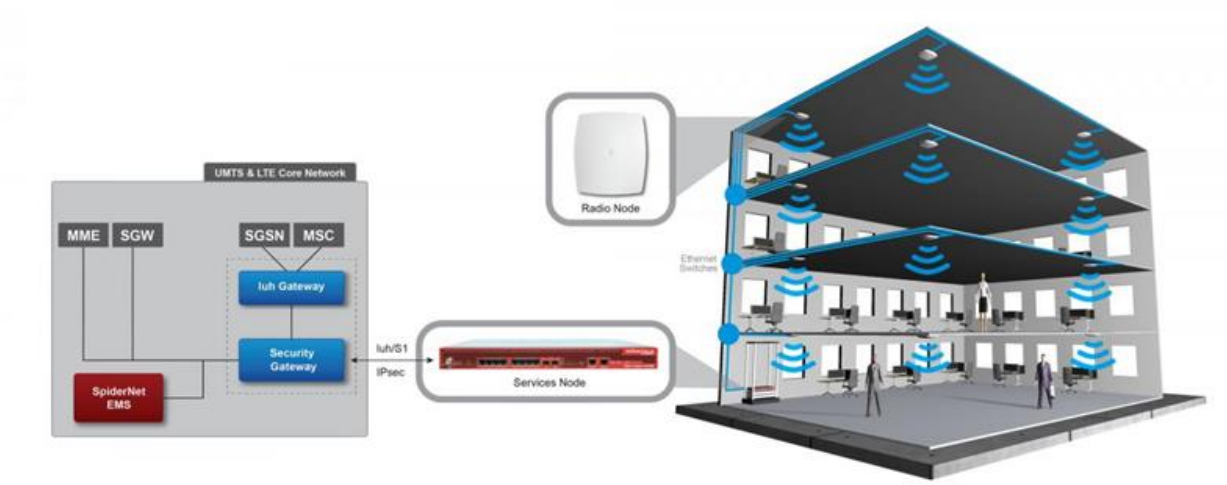
A key aspect of a residential femtocell is that it must be "plug and play" since consumers will likely be self-installing them at home. It must be easily installable and provision automatically. With small coverage requirements, Residential femtocells typically operate below 2x50mW or 100mW composite power. Moreover, simultaneous user capacity is low, around 8-16 simultaneous connections. For some operators with limited LTE coverage, 3G/LTE dual-mode support is still needed, but this is quickly phasing out in developed markets such as North America, Japan, Korea, and China.

Source: Samsung

Figure 16. Residential Femtocell

Enterprise Small Cells

Enterprise applications increasingly use a local controller to coordinate multiple small cells, to assist in the local breakout, caching of local data, integration with the company's server or LAN, and to facilitate LTE-Advanced features such as CoMP and eICIC. This approach facilitates deployment of the radio units throughout the building very quickly because the controller box in the IT closet feeds Cat-5 or Cat-6 cabling which can be deployed very quickly over the ceiling tiles in most office buildings.



Source: SpiderCloud /Corning

Figure 17. Example of a Controller-based Enterprise Small Cell Architecture

While a few low-power "standalone" femtocells are fine for smaller venues without significant impact due to co-channel interference, it is difficult to tackle large venues where many enterprise small cells can "interfere" with one another. The controller-based approach works best in these scenarios, where coordination between multiple radio nodes can be handled by a controller. Over time, we expect the controller element can become a platform for the enterprise to run value-added MEC services such as instant messaging or enterprise-specific applications.

Distributed Radio Systems (DRS)

Distributed Radio Systems (DRS) like Huawei's LampSite, Ericsson's Radio Dot, ZTE's Qcell, and Nokia's AirScale Indoor Radio all share the same architecture as shown in the figure below. The DRS takes the C-RAN architecture one step farther than other small cells. Instead of the RRH feeding an antenna directly, the RRH (Remote Hub in the DRS architecture) leads to a series of distributed RF antenna nodes (i.e., remote radio units or RRUs) to distribute RF signals "deep" within an indoor venue. This is very similar in concept to other "distributed" systems like active DAS. While the architecture and

functional aspects of DRS is similar to active DAS systems, we generally view DRS as a "single-operator" system vs. "multi-operator" capabilities for DAS.

A DRS system consists of a baseband unit (BBU), a radio head unit hub (Remote Hub), and multiple remote radio units (RRUs). For example, in Ericsson Radio Dot parlance, the Remote Hub is called *Indoor Radio Unit,* and the RRUs are simply the *Radio Dots*. In Huawei LampSite parlance, the Remote Hub is simply noted as *RHUB,* and the RRUs are noted as *pRRUs*. In the DRS architecture, the same macro BBU can be used to serve the indoor small cell network. The Remote Hub is essentially an aggregation point for multiple RRUs dispersed throughout a venue to provide indoor network coverage. On the downlink, the Remote Hub transmits to all RRUs in a given single frequency network. On the uplink, it sums up and forwards the uplink traffic from multiple RRUs to the BBU. The RRUs convert IF to RF and transmit over the air. It should be noted that the IF connectivity over Cat 5/6 structured cabling between Remote Hub and RRUs is proprietary CPRI. Hence, you can't mix and match DRS network components between vendors. (The O-RAN initiative is basically trying to standardize the BBU/RRU interface.)

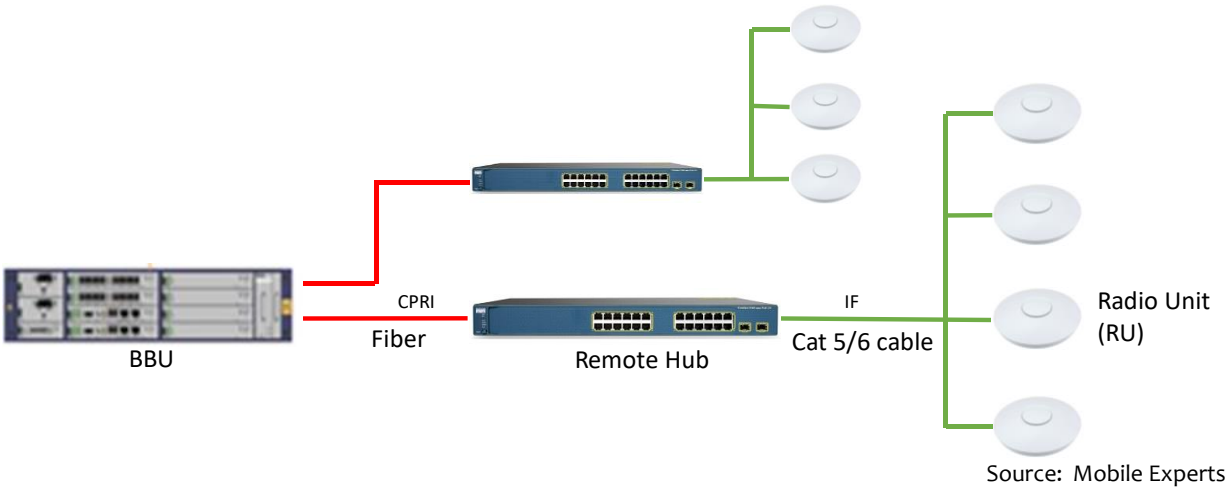


Figure 18. DRS Indoor Small Cell Architecture

Even though the DRS vendors have introduced a "multi-operator" feature whereby multiple operators can share a DRS system already deployed in a building or venue via optional "RF converter" box where RF signal can be "translated" into proprietary CPRI, we believe this will have a limited appeal in competitive markets like North America where operators are less prone to sharing active network assets.

Wireless Relay Indoor Small Cells

Wireless relay small cells like Sprint's Magic Box have been a big contributor to Carrier Indoor deployments last year. Instead of wireline backhaul, the Wireless Relay Small Cell uses LTE UE Relay feature for backhaul and indoor small cell for access. On the eNodeB access side, the small cell feature resembles a typical integrated Carrier Indoor Small Cell

with 2T2R and 100-200 mW transmit output power per stream. The UE Relay (CPE) provides wireless backhaul connection to the Macro network using dedicated spectrum. For a spectrum-rich operator like Sprint, it has provided a quick time-to-market solution to expand network capacity and coverage in key places where subscribers consume data.

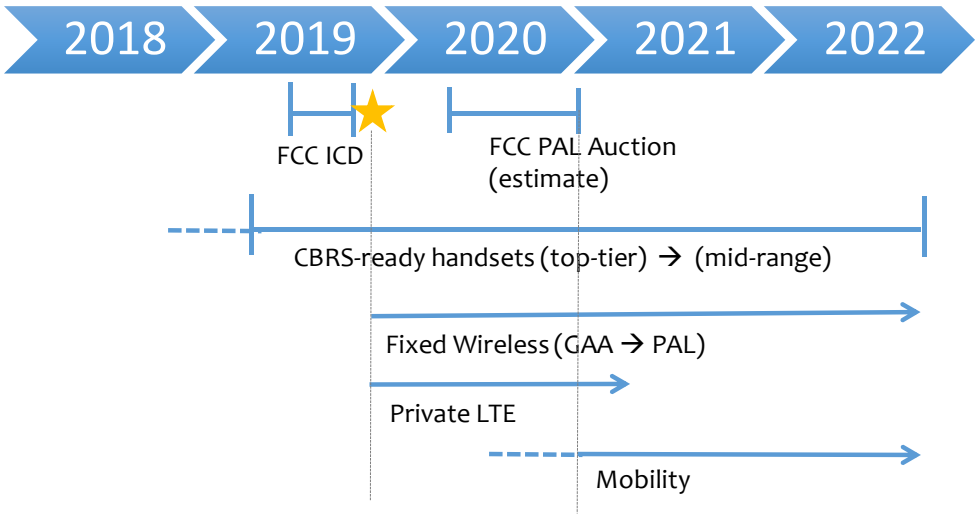
Unlike repeaters, the Wireless Relay small cell uses a dedicated channel to regenerate signals, thus reducing noise and interference often found in traditional repeater systems. They are completely separate base stations that happen to use dedicated spectrum for wireless backhaul.

CBRS – Enabling Shared Spectrum Use for All

The Citizen Broadband Radio Service (CBRS) in the 3.5 GHz (3550 – 3700 MHz) band has created a lot of excitement across many different segments within the wireless industry over the past couple of years, including:

- Fixed wireless access for in-home broadband;
- Mobile capacity augmentation for mobile operators;
- Mobile offload for cable MVNO;
- Neutral host in-building wireless; and,
- Private LTE for enterprise applications.

A key element of the CBRS spectrum sharing architecture is the *Spectrum Access System* (SAS). A SAS maintains a database of all CBRS base stations, formally referred to as *Citizens Broadband Radio Service Devices* (CBSDs), including their tier status, geographical location, and other pertinent information to coordinate channel assignments and manage potential interferences. To mitigate possible interference to tier 1 military radar systems, environmental sensors known as the *Environmental Sensing Capability* (ESC) are deployed in strategic locations near naval stations, mostly along coastal regions, to detect incumbent activities. When incumbent use is detected, the ESC alerts the SAS, which then directs CBSDs utilizing impacted CBRS channels in that area to move over to other channels. The SAS enforces the three-tier – i.e., Incumbent, Priority Access License (PAL), and General Authorized Access (GAA) – spectrum sharing mechanism via centralized, dynamic coordination of spectrum channel assignments across all CBRS base stations in a given region.



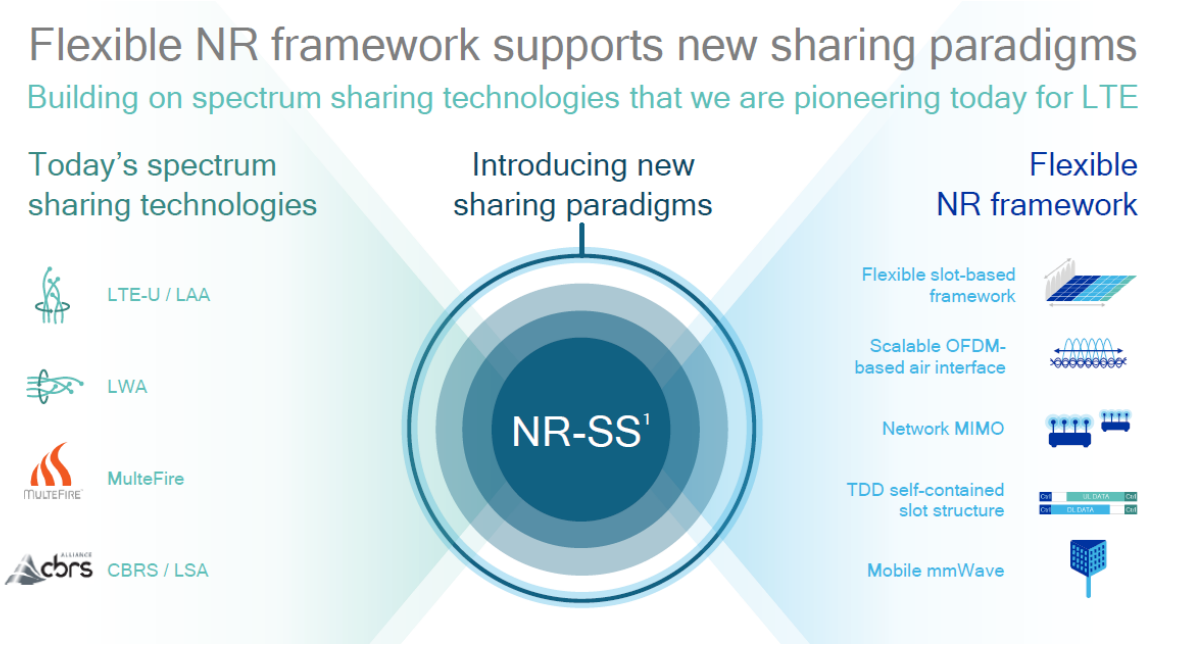
Source: Mobile Experts

Figure 19. CBRS Commercialization Timeline (Estimate)

The CBRS ecosystem has been maturing and is expected to go commercial in the second half of this year. The ESC testing has been completed, and the completion of SAS testing is almost complete. Once the FCC, NTIA, and DoD give their approvals, the CBRS Initial Commercial Deployment (ICD) is expected to start sometime in the second quarter this year. After a couple of months of ICD trials, we expect the FCC and other government agencies to formally certify the CBRS commercial operation, and the commercial operation is expected to start sometime in the third quarter of this year. At the latest, we expect commercial CBRS operations to ramp up starting 2020. While we see CBRS-capable handsets to come to market, we expect Fixed Wireless Access and Private LTE to be two primary use cases from the start. The full mobility use case will likely ramp up as we get close to the PAL auction likely in the second half of 2020 and possibly early 2021.

5G NR in Unlicensed – LAA and MulteFire 2.0

The 3GPP Release 16 is expected to define 5G NR use in the unlicensed spectrum – similar to LTE use in unlicensed which brought about LAA, CBRS, and MulteFire innovations in the marketplace. While it is simply too early to predict how this new 5G spectrum sharing mechanism under study at 3GPP will impact the Small Cells marketplace, we can look to LAA and CBRS impact as guideposts in its possible impact. By our estimate, the LAA small cell shipments have been meaningful for tier 1 vendors as spectrum-constrained operators in the USA have taken to LAA in key markets to boost user speeds. At a high level, 5G NR in unlicensed spectrum, or what Qualcomm calls "NR-SS" (NR Spectrum Sharing), appears to exploit the flexible frame structure already defined in 5G NR and the increased probability of spatial diversity and orthogonality in the context of millimeter wave with narrow beams to share the spectrum simultaneously and other novel methods.



Source: Qualcomm

Figure 20. 5G NR Spectrum Sharing

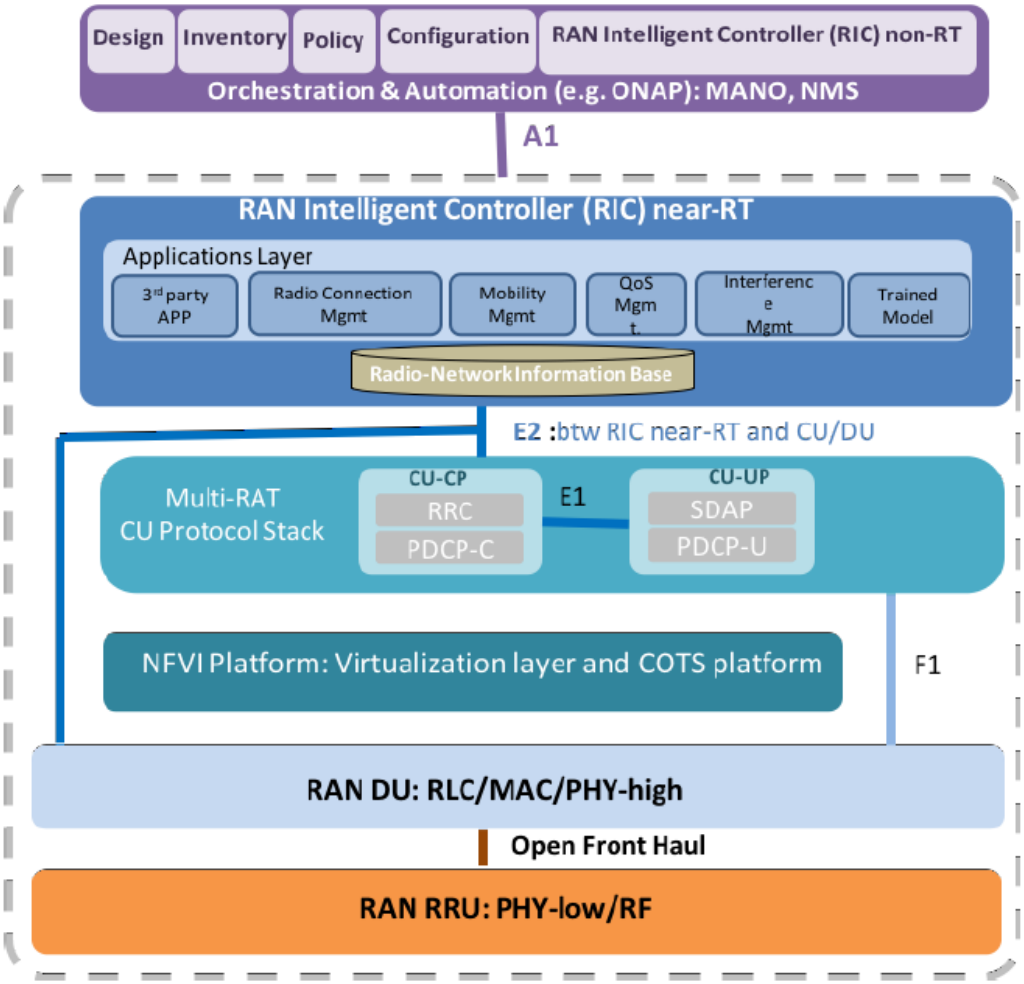
While it is too early to guess how 5G NR operation in the unlicensed spectrum will be adopted, we are keen to follow how the 5G NR may be positioned in the upcoming 6 GHz (5.925 – 7.125 GHz) unlicensed spectrum ruling. We don't expect major operators to seriously consider unlicensed spectrum to run their services, but in certain use cases such as Private 5G applications like factory automation, we believe the 5G NR operation in the 6 GHz band may yield a huge dividend 4-5 years from now. The 1.2 GHz of "free" spectrum will be hotly contested for sure.

O-RAN – Small Cells in "Open" RAN

A constant "tug-of-war" between operators and vendors has been at play for decades in the telecommunications industry. Operators want open standard products so that they can mix and match solutions from multiple suppliers so that they have the upper hand in price negotiations. Of course, vendors are against that. They like to maintain some level of proprietary differentiations to keep their product solutions entrenched within operator networks so that the operators have to come back to them for system upgrades and maintenance. As the industry embarks on 5G, operators are keen to "open" their RAN networks to lower prices on their RAN CAPEX spends. But, more importantly, they want to maximize "open source" software and other hardware components to lower the OPEX, which is the main driver in their TCO calculations.

The operators' latest "open source" movements related to RAN have converged on the Open RAN (O-RAN) Alliance which aims to lead the mobile industry towards open, interoperable interfaces and RAN virtualization. Secondarily, it aims to specify API

interfaces to adopt open source software and maximize the use of common-off-the-shelf hardware based on merchant chipsets that can be sourced by multiple hardware systems developers. In contrast, many leading RAN vendors have owned chipset solutions that can't be sourced by other system vendors. For example, Nokia isn't interested in sharing its Reefshark chipset with others. Likewise, Huawei has its own chipset solution that differentiates its RAN products from its competition. There isn't a merchant SoC chipset vendor who supplies macro-class SoC to multiple suppliers today.



Source: O-RAN Alliance

Figure 21. O-RAN Reference Architecture

As illustrated in the figure above, the O-RAN Alliance is working to standardize the "Open Fronthaul" interface between the Distributed Unit (RAN DU) and the Remote Radio Unit (RAN RRU). This is analogous to the "green" interface between the "Remote Hub" and the "Radio Unit" in the DRS architecture as shown in Figure 15. Today, those "green" interfaces are proprietary for each vendor who supply DRS units for indoor small cell

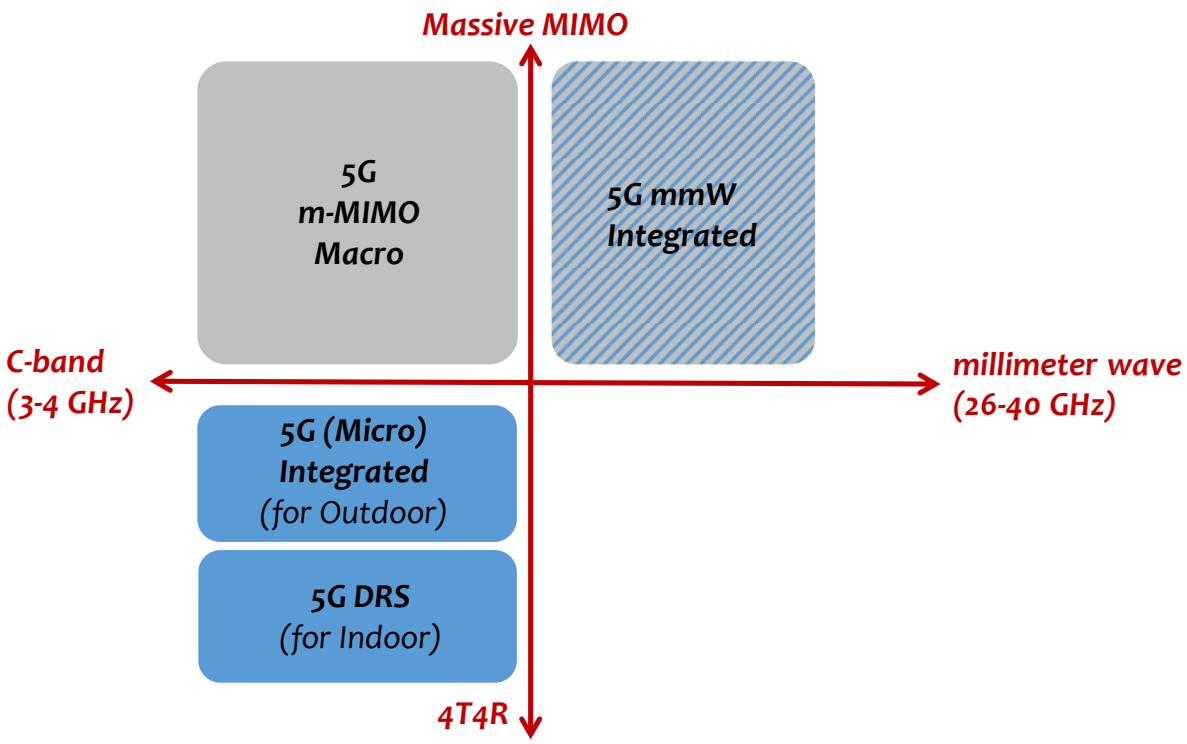
deployments in China. In other words, an operator can not use Nokia's Remote Hub with Huawei's pRRU radio unit.

While we remain somewhat skeptical that the tier 1 operators will use O-RAN radio gears in huge volumes in the next 3-4 years, we expect them to deploy O-RAN gear in certain situations. For example, we expect some tier 1 operators to leverage O-RAN gear in rural deployment scenarios where low-cost CAPEX and OPEX deployments are key to making business cases work. Moreover, we expect to see a larger number of O-RAN small cells indoor deployments especially by enterprises for private LTE applications that do not require lots of mobile-centric features that are often times kept closed by top vendors. With most global tier 1 operators supporting the initiative, we believe that the operators are keen to support the initiative, and some tier 1 vendors will be forced to participate or lose some portions of lucrative 5G contracts. Smaller operators and third-world operators may also be more willing to adopt O-RAN equipment.

5G (Sub-6GHz and Millimeter Wave) Small Cells

There is a consensus that 5G NR will run on the C-band (3-4 GHz) using massive MIMO to extend 5G coverage in line with the LTE coverage map. We are hearing that 64T64R massive MIMO running in the C-band provides a similar coverage footprint as LTE 4T4R in the 2GHz band. Hence, we believe 5G NR will be applied to massive MIMO active antennas to achieve the maximal 5G coverage/capacity performance. So, what about 5G small cells? Here, we believe it is important to distinguish a 5G small cell by frequency band because that will determine what types of antenna configuration will be applied and how those 5G small cells will be used.

First, we believe 5G small cells running in the sub-6GHz band will use 4T4R at highest possible power without sacrificing on physical dimensions and power consumption. Based on the popularity of DRS architecture in indoor small cell deployments, we believe 5G DRS units like Huawei Lampsite will operate at up to 4 x 250 mW to match the LTE DRS coverage footprints. For outdoor deployments, 5G (sub-6GHz) small cells may run up to 4 x 5W to provide maximal coverage footprint without sacrificing on power consumption and physical dimensions.



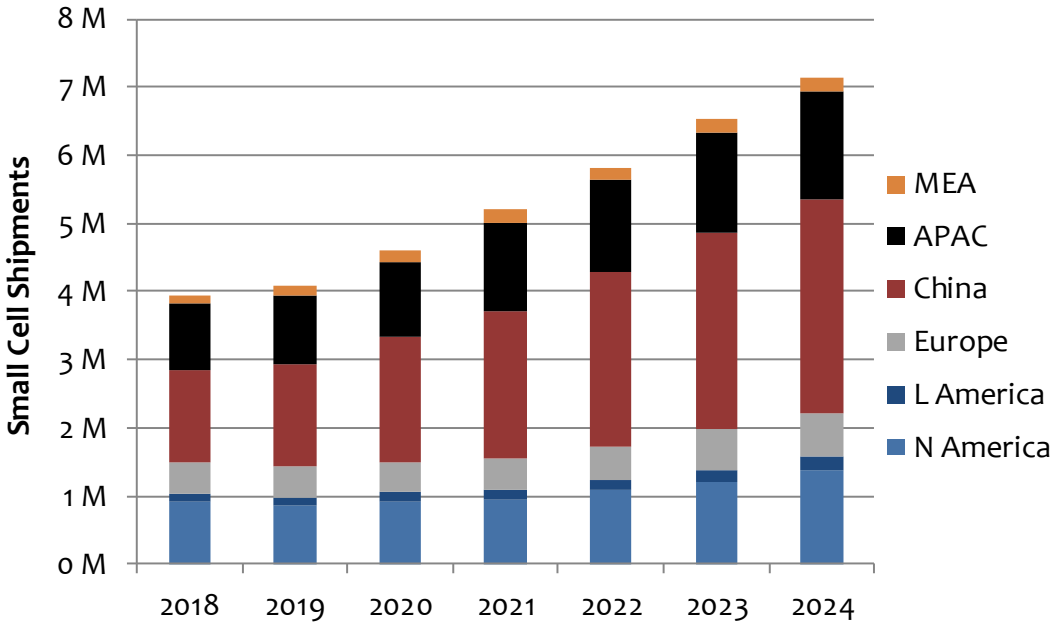
Source: Mobile Experts

Figure 22. 5G Small Cells positioning by Band and MIMO configuration

The 5G NR deployment in the millimeter wave band will be different. With 64T64R or 32T32R massive MIMO, we see 5G millimeter wave radios that are compact but operate at significantly high EIRPs in the range of 50-60 dBm. Despite the high output transmission power, the effective coverage area will be limited due to propagation attenuation at such high-frequency bands. While these 5G millimeter wave radios with massive MIMO have hefty transmission output power ratings, they have typical small cell dimensions and effective coverage areas. As noted in the *Preface* section in the report, we do not track this 5G millimeter wave "small cells" in this report.

5 REGIONAL OUTLOOK

As noted in the *Preface* section, our forecast of the Small Cells shipments does not include millimeter wave radios -- though small in both form factor and network coverage. Hence, reported small cell shipments in this report are meaningfully lower than last year's report – especially in North America and APAC regions where we expect meaningful millimeter wave RAN deployments. Despite this change, an overall picture of the three dominant regions namely North America, Asia-Pacific, and China, are expected to lead the small cell market in the foreseeable future as the market transitions to 5G. Market drivers for small cell deployments differ by region, depending on the lifecycle of 4G/5G technology transition, C-band vs. millimeter wave, and competitive dynamics, but the macro driver is the same across all the markets – mobile traffic continues to grow, and competition is forcing operators to invest. And, small cells remain an economical approach for many operators and enterprises to expand coverage and capacity in several use cases.



Source: Mobile Experts

Chart 3: Small Cell Forecast, Global by Region, 2018-2024

North America

North America region, specifically the USA, is an important market for the Small Cell market. Not only do American operators wield large capital budgets, but the mobile traffic demand is very strong driving the operators to continue network investments leveraging multiple tools, including small cells, to address the underlying demand. With different market positioning and assets, each operator is pursuing a slightly different path toward "LTE-to-5G" network investments with different implications for major tier 1 telecom infrastructure and small cell specialist vendors.

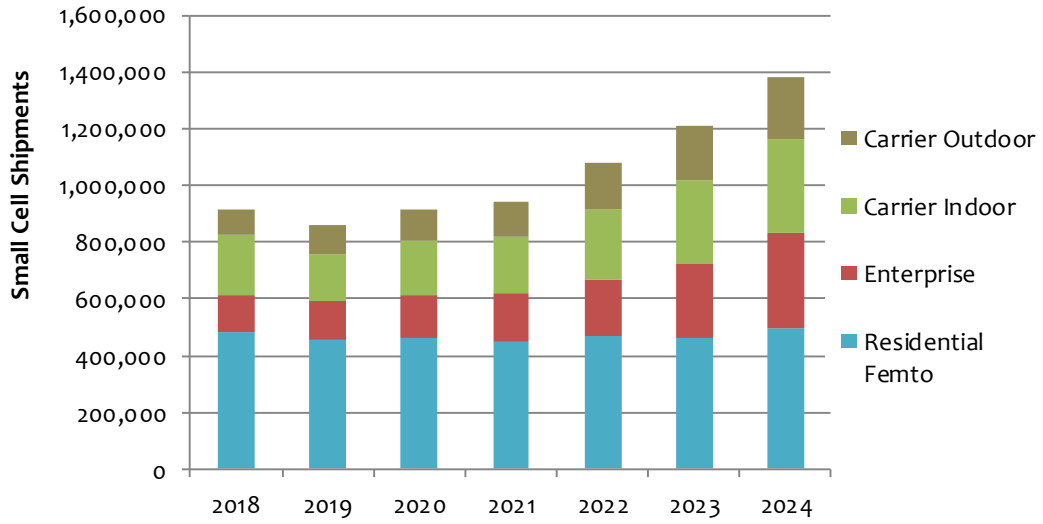
While Verizon's "small cell" activities largely center around millimeter wave spectrum deployment for its *5G Home* fixed wireless service and 5G mobile service, we expect Verizon to continue relying on its residential and SOHO LTE femtocells and strategic deployment of LAA and CBRS small cells to expand network capacity in traffic hotspots. We hear about robust LAA and CBRS small cell deployments in North America today which isn't too surprising given that spectrum exhaust in the sub-3 GHz range has been an on-going concern in this market for some time. The operators are finding interesting ways to leverage the unlicensed 5GHz, and soon, the shared 3.5 GHz CBRS band to expand network capacity – which has been a boon to the small cell market growth in the region. While these are necessary, near-term remedies for the operators, 5G deployments in the "mid" bands including the 3.5 GHz CBRS band and the 3.7-4.2 C-band will be the primary focus for the majority of the U.S. operators in the near and mid-term.

Sprint's challenging position in the marketplace over the past several years has forced it to seek non-conventional ways to expand network coverage and capacity. The company has been an active proponent of small cells, by necessity, to expand its network capabilities. In dense urban markets, it has deployed thousands of high-power outdoor small cells that are small enough to deploy on city fixtures to provide network relief. Moreover, it has deployed hundreds of thousands of wireless relay small cells (e.g., Magic Box) to expand network coverage inside enterprise venues. While the operator has deployed a big chunk of these in SOHO residential settings as well, we count them under "Carrier Indoor" small cells instead of residential femtocells. Going forward, we expect the robust deployment of these carrier indoor products to wane somewhat (if the T-Mobile/Sprint merger goes ahead as we currently assume in our model). Moreover, Sprint has been active in the deployment of strand-mount small cells between utility poles to expedite siting challenges that have hampered the small cell deployments in many markets. We believe the strand-mount small cell deployment, in collaboration with cable operators including Altice, is closely tied to Altice's entry into the mobile wireless market.

While it awaits a "green light" from the FCC and Department of Justice on its pending merger with Sprint, T-Mobile's small cell strategy largely centers around its residential femtocell deployments. With robust 2.5 GHz "mid-band" spectrum that it would gain from the Sprint merger, we expect T-Mobile to be very focused on massive MIMO in the 2.5GHz band at a macro layer to expand network capacity instead of focusing on small cells. However, we expect the operator to be keen to leverage the 3.5GHz CBRS band as a carrier aggregation layer to expand network capacity in traffic hotspots. It certainly won't be shy to take advantage of the "cheaper" spectrum in the 3.5GHz CBRS band if it comes available.

AT&T's 5G transition has been publicly led by its "5G Evolution" marketing campaign which leveraged LTE-Advanced features like 4x4 MIMO, 256 QAM, and 3 or more carrier aggregation to increase network capacity and average speed improvement in markets where these features have been deployed through network software upgrades and in

certain cases, LAA small cell deployment to provide additional spectrum in the 5 GHz unlicensed to boost spectrum capacity to allow carrier aggregation to boost average user speeds. According to AT&T, it has over 400 "5G Evolution" markets and plans to expand "5G Evolution" to 500 markets by mid this year. Of the 400 markets that are "on the way to 5G," about 40 markets have LAA deployed. This implies that LAA is strategically deployed in traffic hotspots, likely in urban areas where traffic demand is the greatest. With its FirstNet network deployment, AT&T has the added benefit of 700 MHz (Band 14) spectrum to aid in its network capacity expansion in addition to getting funding from the FirstNet.



Source: Mobile Experts

Chart 4: Small Cell Forecast, North America, 2018-2024

We expect 2019 to be a transitioning year in North America with a flattish trend in the near term for sub-6 GHz small cells as reported in this report. It should be carefully noted however that the overall "5G small cell" activities around siting and millimeter wave radio deployments will be quite active this year and beyond. Three major industry developments are driving this trend:

- The pending T-Mobile/Sprint merger is expected to temper somewhat the high growth of small cell deployments at Sprint that we observed last year. With our belief (guess) that the merger will eventually be approved in the second half of this year, we expect the combined New T-Mobile to tamper Sprint's small cell strategy around "Mini Macro" outdoor small cells and "Magic Box" indoor units.
- The major operators' initial 5G investments on "small cell" sites on the street "furniture" like light poles, utility poles, and rooftops will largely transition to millimeter wave radios as they look to harness hundreds of 28 and 39 GHz spectrum that they already hold. Moreover, as the on-going millimeter wave spectrum auctions finalize, they will be flush with spectrum and will be eager to deploy them to increase significantly expand network capacity. (Since the operators' 5G

millimeter wave radio investments are not reflected in this report[2], the remainder sub-6GHz small cell forecast shows a flattish trend in the near term.)

- The delay in CBRS commercialization (in our forecast last year) has hampered deployment of Carrier Outdoor small cells for capacity augmentation by mobile operators, and to a lesser degree by cable operators to aid in their MVNO mobile business case. While the CBRS commercialization timeline now looks to start in the third quarter this year, the CBRS band utilization via small cells is expected to ramp earnestly in 2020.

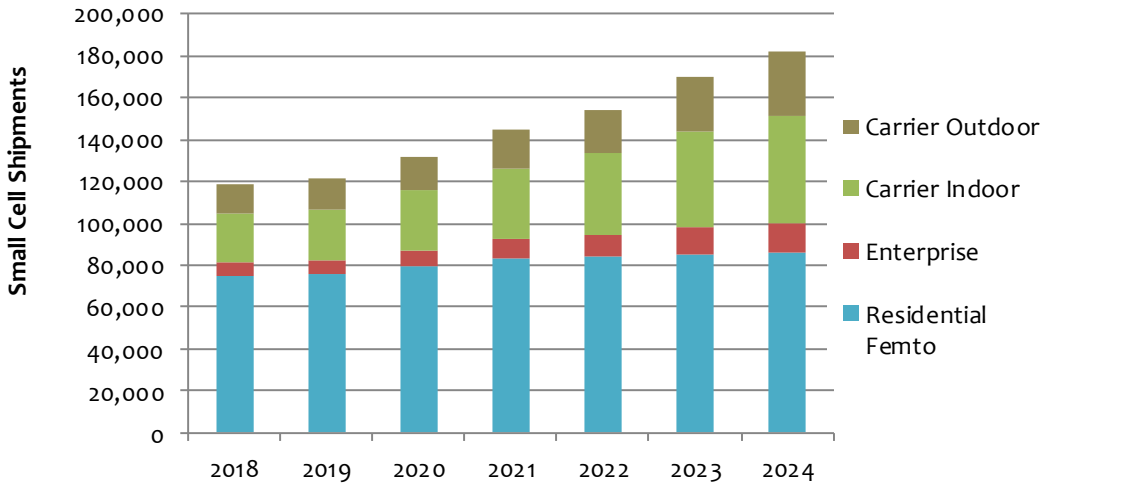
The residential femtocell shipment will remain steady during our forecast period as the 5G Non-Standalone (NSA) network transition will greatly rely on the LTE network as a baseline network platform for much of coverage signaling. In the meantime, the growing CBRS deployment by both mobile and cable operators and enterprises for private LTE applications will drive all other small cell segments including Carrier Indoor, Carrier Outdoor, and Enterprise small cells. While a major portion of mobile operator small cell activities will center around millimeter wave network coverage, cable operators and enterprises are expected to boot small cell activities in the later half of our forecast period especially as CBRS PAL auction comes to reality sometime in 2021/2022.

Latin America

Not much has changed in Latin America over the past year. While LTE macro network investment continues to be made, the mobile traffic density hasn't reached the levels that warrant small cell investments in many locations. Meanwhile, small cells are being deployed in highly dense public venues like sporting stadiums, high-end office buildings, and major government facilities. Here, DRS systems like Huawei's Lampsite and Ericsson Dot have found a receptive audience where operators are willing to make a direct investment to provide a good user experience in those highly trafficked areas.

Another bright spot of small cell activities is the use of Hi-Power Carrier Outdoor Small Cells that provide macro-like coverage at a lower cost than typical LTE macro base stations. The continued economic "headwind" in the region, especially in Brazil and Argentina, is forcing operators to look to lower cost alternatives to expand network capacity. They are increasingly looking to these "mini macro" Small Cells to provide coverage and capacity in "hot spot" locations in key urban and rural areas where the high-cost macro base station investments have been prohibitive. Nokia's Mini Macro and similar products from Parallel Wireless, Airspan, and others are finding a receptive audience from budget-constrained operators and organizations. In addition to Hi-Power Carrier Outdoor small cells, some major tier 1 operators are expected to carry out O-RAN network trials in the next few years to see whether the O-RAN promises of lower-cost RAN alternatives can be realized or not.

[2] Our 5G Millimeter Wave report reflects our forecast of 5G millimeter wave investments.



Source: Mobile Experts

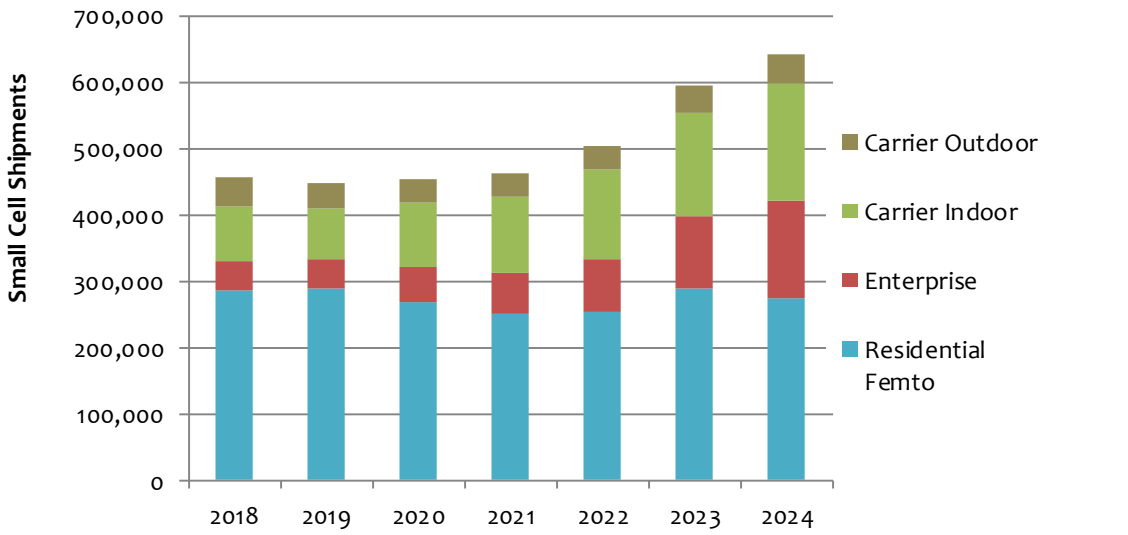
Chart 5: Small Cell Forecast, Latin America, 2018-2024

Europe

Due to highly competitive market conditions, partially a result of 'hands-on' regulatory regimes in the region, the fixed mobile convergence trend has been far more prevalent in this region than elsewhere. With lower ARPU than the US market, converged integrated operators have utilized "quad play" services retain subscribers. In that regard, residential femtocells have played an integral role.

Also, we see operators increasingly utilize Carrier Indoor small cells to provide in-building wireless coverage in key venues. We are seeing a selective use of DRS systems at some venues in the competitor's macro footprint areas. For example, LampSite deployments at a Daimler building in Germany, football (soccer to the US fans) stadiums in Spain, UK, and elsewhere are some of the examples of increasing DRS deployments in the region. While the scale of DRS or Carrier Indoor small cell deployments in the region is nowhere close to what's happening in China, the DRS deployments, often in competitors' macro footprint, shows a maturing ecosystem in the region.

The 5G momentum is starting to pick up in the region, and regulators are starting to open up spectrum for 5G in Europe. While the major vendors would like to see a faster pace of 5G investments in the region, we are starting to hear major operators starting to plan out their 5G strategies and network deployment plans. We expect massive MIMO in the 3.5 GHz C-band to be the primary means for 5G network coverage and capacity expansion. Based on early field trials, massive (64T64R) MIMO in C-band would likely provide similar coverage as LTE in the current macro grid densities in the region. As a result, our forecast for Carrier Outdoor small cells has been reduced from our view last year.



Source: Mobile Experts

Chart 6: Small Cell Forecast, Europe, 2018-2024

The pace of small cell growth will come from Carrier Indoor deployment at key venues and increasing adoption of Enterprise small cells in the context of private LTE and 5G applications in vertical sectors like manufacturing, transportation port operations, and public safety. The dedicated 5G spectrum for industrial use cases in Germany is a good guidepost of this trend. We expect the Private LTE and 5G momentum to pick up starting in 2022 as 3GPP Release 16 standards wrap-up and standards-based products come to market in volume.

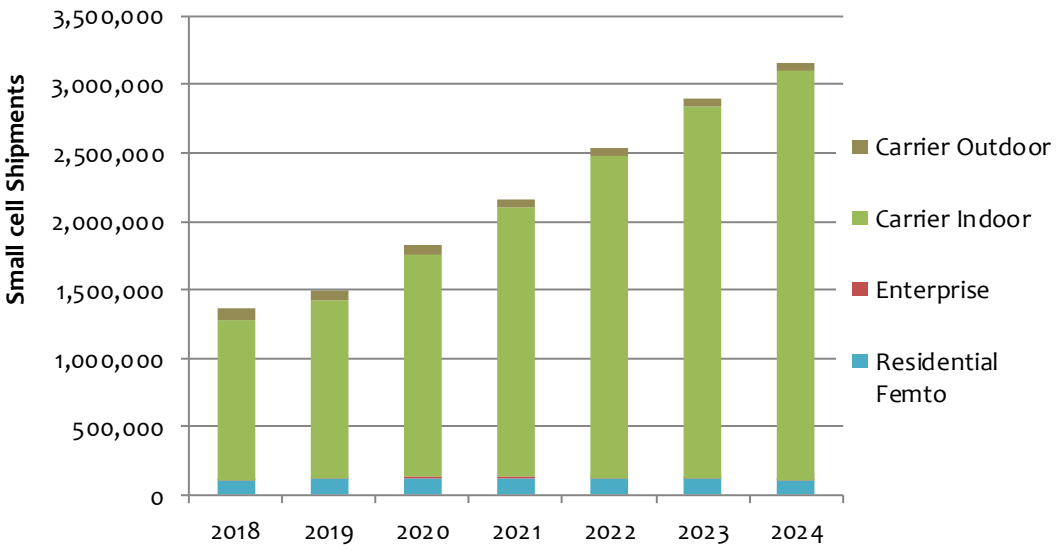
China

In China, the small cell activity centers around DRS deployments. All three Chinese operators have pretty much standardized around the DRS architecture which distributes low-power (~200mW per antenna) remote radio units in a centralized, hierarchical manner using lots of hubs tied to macro-class BBU to distribute remote radio units further deeper inside a building or venue. Under the "Digital Indoor Systems" (DIS) banner, all major vendors have adopted this architecture to sell their gear in this important market. Huawei's LampSite, ZTE's Qcell, Ericsson Radio Dot, and Nokia AirScale Indoor Radios are products that all fall in this category of small cells.

While we continue to expect residential LTE femtocells and Hi-Power Carrier Outdoor units to dot the small cell marketplace in China, the volume of these units pales in comparison when the operators are keen to leverage DRS systems to expand network capacity inside buildings. Less costly residential femtocells and Hi-Power Carrier Outdoor units are welcomed by provincial operator subsidiaries who have limited budgets and need lower-cost mobile infrastructure solutions to meet both coverage and capacity demands in outer

regions. Moreover, we see major Chinese operators trialing O-RAN equipment vendors for limited trials to limit the vendor lock-in situation. However, we expect this trend to be limited in its impact especially in outdoor deployment scenarios.

Compared to last year, our view of Carrier Outdoor small cell shipment in China has diminished. In talking with Chinese operators and vendors, it is widely acknowledged that operator use of massive MIMO at the macro layer will limit the need for outdoor small cells, especially in the near term. With a concerted effort by the Chinese operators to leverage DRS systems to address the capacity demand from inside buildings, it appears that massive MIMO deployments outside should be enough to handle most of the 5G use cases without significant reliance on Carrier Outdoor small cells.



Source: Mobile Experts

Chart 7: Small Cell Forecast, China, 2018-2024

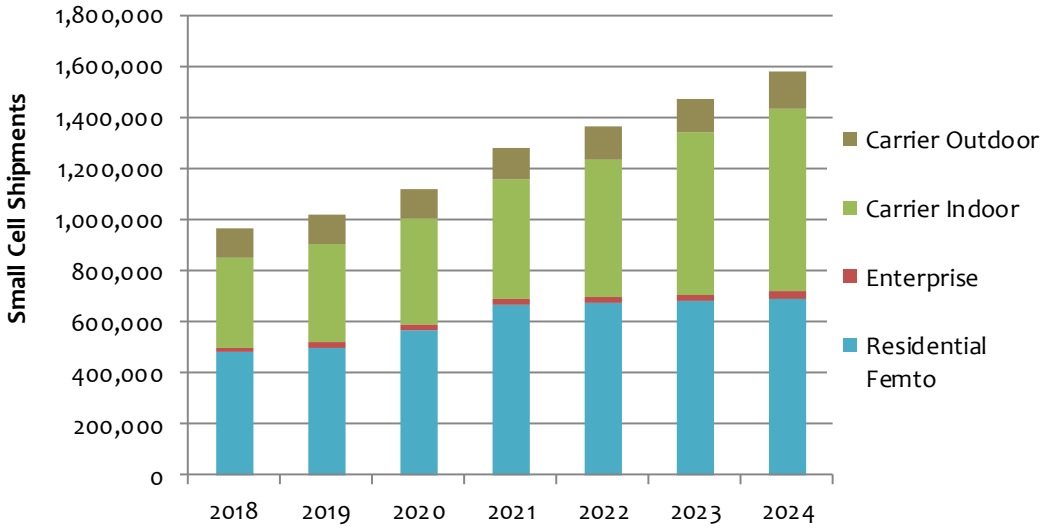
The enterprise small cell market is almost non-existent in China as it is customary for operators to take the lead in in-building wireless projects. The Chinese operators take primary responsibility for providing mobile coverage everywhere – both outdoors and indoors. Hence, we do not forecast any meaningful deployments of Enterprise small cells in China. Rather, we account for enterprise-targeted small cells for China market as a part of Carrier Indoor small cells in our forecast. Almost all Carrier Indoor units for China are DRS radio units.

Excluding residential femtocells, China is the single largest market for carrier-grade small cells as all three operators drive towards DRS-based Carrier Indoor small cell deployments. With robust fiber infrastructure and commercial venues that are mostly new, carrier small cell deployments for both indoor and outdoor projects are much easier for the operators in China compared to their peers in North America and Europe. Centralized capitalistic

market environment in China has been advantageous for the Chinese operators to quickly ramp up small cell deployment which is in sharp contrast to North American and European peers who face fragmented ecosystem of regulations and infrastructure footprints.

Asia Pacific (excluding China)

India has emerged as an important market for small cells with Reliance Jio's disruptive market entry. In response to Jio's market entry, the Indian mobile market is going through necessary market consolidation, and competitors are expanding their small cell strategy to meet the growing consumer demand. As noted in last year's report, we are seeing evidence of Jio's competitors leaning towards small cells to immediately combat Jio competition. Vodafone-Idea and Airtel appear to be expanding their residential and Carrier indoor deployments. In the near term, we are forecasting Indian operators to leverage LTE femtocells and innovative wireless backhaul small cells to expand coverage and capacity.



Source: Mobile Experts

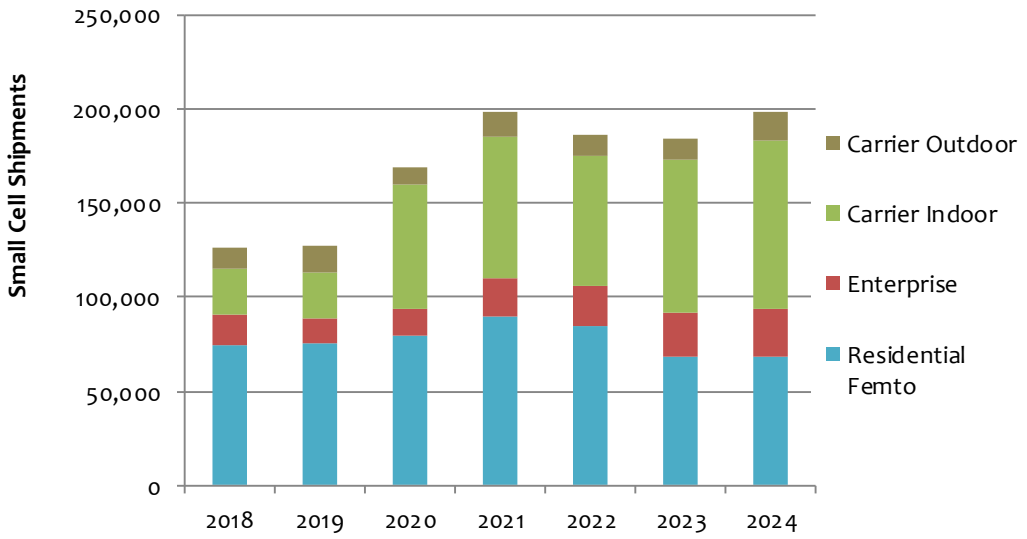
Chart 8: Small Cell Forecast, APAC, 2018-2024

For the rest of APAC region, especially in Southeast Asia, CRAN-based DRS units like Huawei's LampSite and ZTE Qcell are expected to make up a large portion of carrier indoor deployments. Also, LTE femtocells remain a vital infrastructure solution for many operators in mature broadband markets such as Korea and Japan.

Middle East/Africa

The Middle East region is very diverse. It includes highly urbanized, high-ARPU markets like Dubai and UAE, as well as low-density, low-ARPU markets in Africa. For a highly

urbanized market like Dubai and South Africa, we see increasing adoption of Carrier Indoor and Enterprise small cells to address in-building wireless needs at large tall office buildings, airports, and stadiums. In more rural or poor regions, we see growing interest and adoption of Hi-Power Carrier Outdoor radios to expand coverage and capacity more economically than traditional macro towers.



Source: Mobile Experts

Chart 9: Small Cell Forecast, MEA, 2018-2024

6 EQUIPMENT OUTLOOK

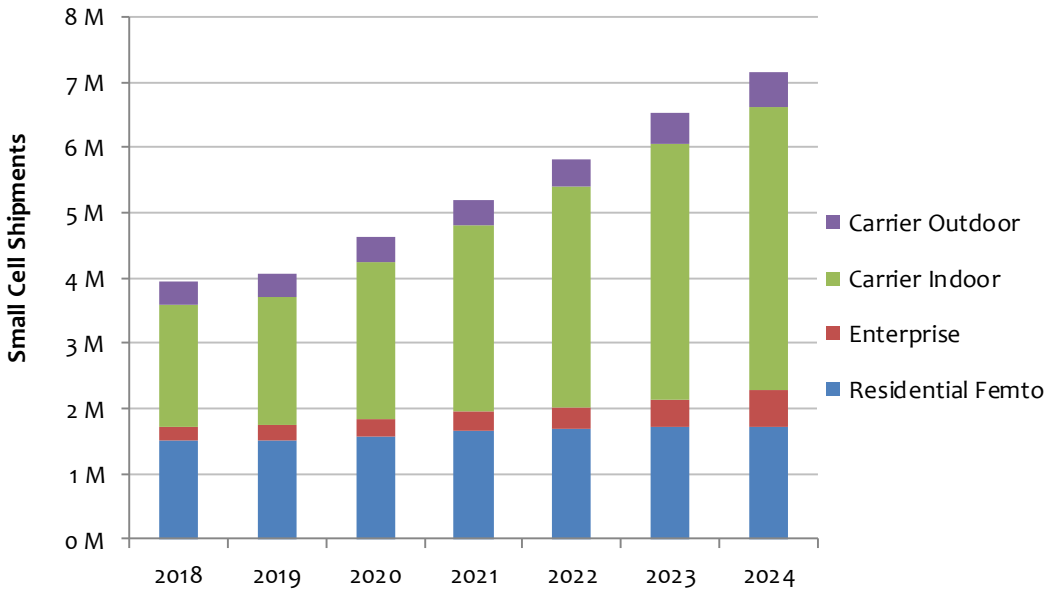
Despite relatively flattish trends in residential femtocells and enterprise segments, the overall small cell shipment grew last year from the year before, from continued growth in Carrier Indoor deployments in the China and APAC regions and Carrier Outdoor deployments in North America. With strong mobile data traffic growth in those regions, operators have been using interesting deployment models to satisfy the growing demand. The DRS-based Carrier Indoor small cells, found mostly in China, will drive the bulk of the small cell shipments as all major telecom infrastructure vendors including Huawei, Ericsson, Nokia, and ZTE have now, all adopted this approach and are expected to have 5G versions of these low-power radio units for indoor deployments this year. Meanwhile, in North America, operators are using various Carrier Outdoor deployment models including C-RAN based Remote Radio Heads, wireless relay small cells, and strand-mount small cells to expand network capacity more expeditiously in places where siting challenges exist. Continued operator investments in carrier indoor deployments, CBRS ecosystem ramp in the USA, and enterprise adoption of Private LTE and 5G applications will continue to drive the small cells market (even if the millimeter wave infrastructure investment is excluded in this report).

Small Cell Shipment Forecasts

The overall small cell shipment grew 20% year over year in 2018. Excluding residential small cells, the growth was even more dramatic – over 40% year over year! The bulk of the growth came from the Carrier Indoor segment, driven by the continued investment of DRS units in China and wireless relay small cells (e.g., Sprint's Magic Box) in North America and parts of the APAC region. In addition, Carrier Outdoor units including pole- and strand-mount outdoor units have been deployed in North America and other regions to address capacity needs in strategic traffic hotspots. Furthermore, we have observed increasing use of Hi-Power Carrier Outdoor small cells by operators in both urban and rural markets in most regions. The adoption has been especially strong in the North and Latin American regions where operators look to these high-power outdoor units with macro-like reach and capacity.

The Carrier Indoor small cell unit shipments increased over 50% year over year in 2018 with a longer-term growth outlook of 15% CAGR from 2018 to 2024. With the 3.5 GHz C-band as a primary baseline for 5G network deployments and the Chinese operators expected to drive further continued investments indoor deployments, the Carrier Indoor segment will drive the volume for overall small cell market in the 5G era. While there is some uncertainty around how the U.S. operators will approach Carrier Indoor segment as they focus on the millimeter wave spectrum deployment in the near term, Mobile Experts believes that carrier deployment in the sub-6GHz band will primarily focus on traditional approaches of leveraging DAS-like architectures with integrated millimeter wave small cells overlaid on top. Since this market study focuses on sub-6GHz, we believe the overall Carrier Indoor trend won't change much.

The Carrier Outdoor small cell unit shipments increased over 17% year over year in 2018 with a longer-term growth outlook of 7% CAGR from 2018 to 2024. The year-over-year growth was largely driven by the continued deployment of integrated base stations and RRHs on poles, cable strands, and building rooftops and facades in urban areas. Moreover, Hi-Power Carrier Outdoor units that provide macro-like performance at lower cost are being increasingly adopted by cost-sensitive operators as they look to expand network capabilities in both urban and rural settings.



Source: Mobile Experts

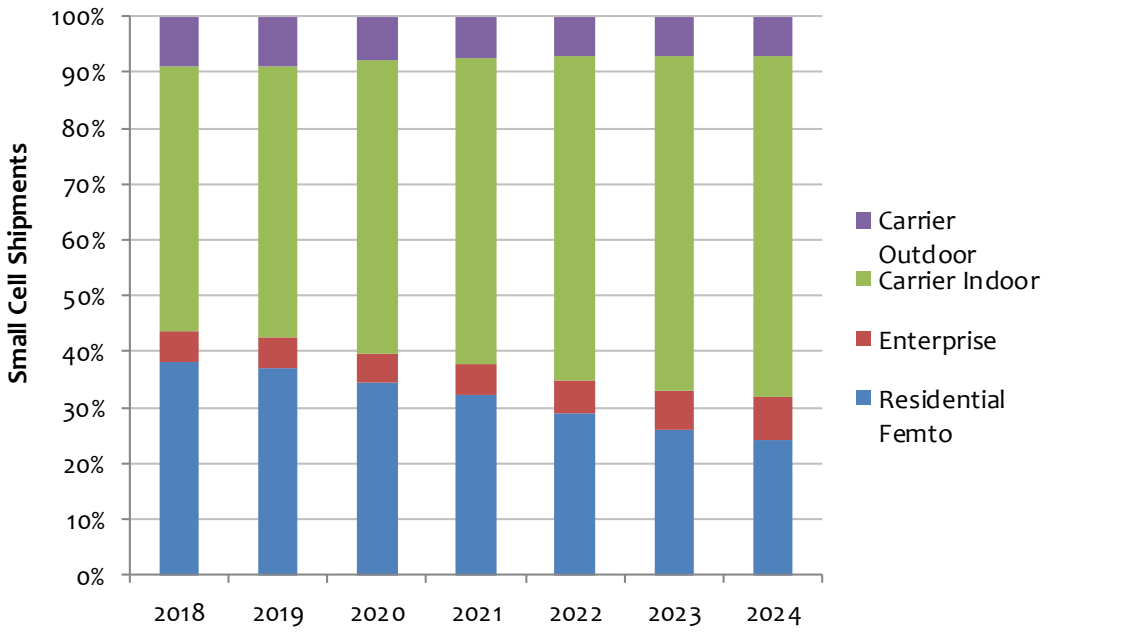
Chart 10: Small Cell Shipment Forecast, by Product Type, 2018-2024

We expect the Carrier Indoor small cell unit shipments to outpace the Carrier Outdoor small cells for a couple of reasons:

1. The majority of mobile broadband services is consumed indoors while the bulk of mobile traffic is handled by outdoor Macro and Small Cell networks; and,
2. Higher path loss for 5G services in higher C-bands (3-4 GHz) will require more indoor networks to handle more of the traffic from within buildings.

An overarching small cell trend continues to shift from residential femtocells to high-performance carrier-grade small cells in terms of volume shipments. Over the ten years from 2014 to 2024, Mobile Experts forecasts the annual shipment of residential femtocells will shift from over 80% to about 25%. Now that our *Small Cells* forecast only focus on the sub-6GHz variety, excluding the millimeter wave radios, we believe the share of Carrier Outdoor small cells will constitute less than 10% of the total unit volume and will gradually decline as the Carrier Indoor unit share takes an overwhelming majority of units in the future. This trend is largely based on our view that 5G network deployments utilizing

massive MIMO on C-band will diminish the need for outdoor small cells, especially in the near term. Over the longer term, we view that operators may extend coverage and capacity via low-power outdoor RRHs, but we believe the unit volume will be minimal.

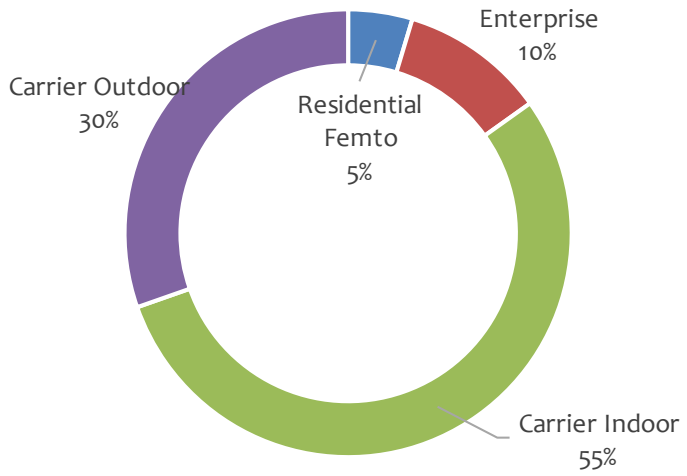


Source: Mobile Experts

Chart 11: Small Cell Shipment Share, by Product Type, 2018-2024

Small Cell Revenue Forecast

Small cell equipment revenue grew 20% year over year to over $2.9B in 2018. In the longer term, the overall small cell equipment market, excluding millimeter wave mobile infrastructure, is expected to grow at 10% CAGR to $5.2B in 2024. In 2018, the Carrier Indoor segment represented 55% of the total, and the Carrier Outdoor segment represented about 30%. The Enterprise and Residential small cell segments constitute the remainder or about $440M in equipment sales.



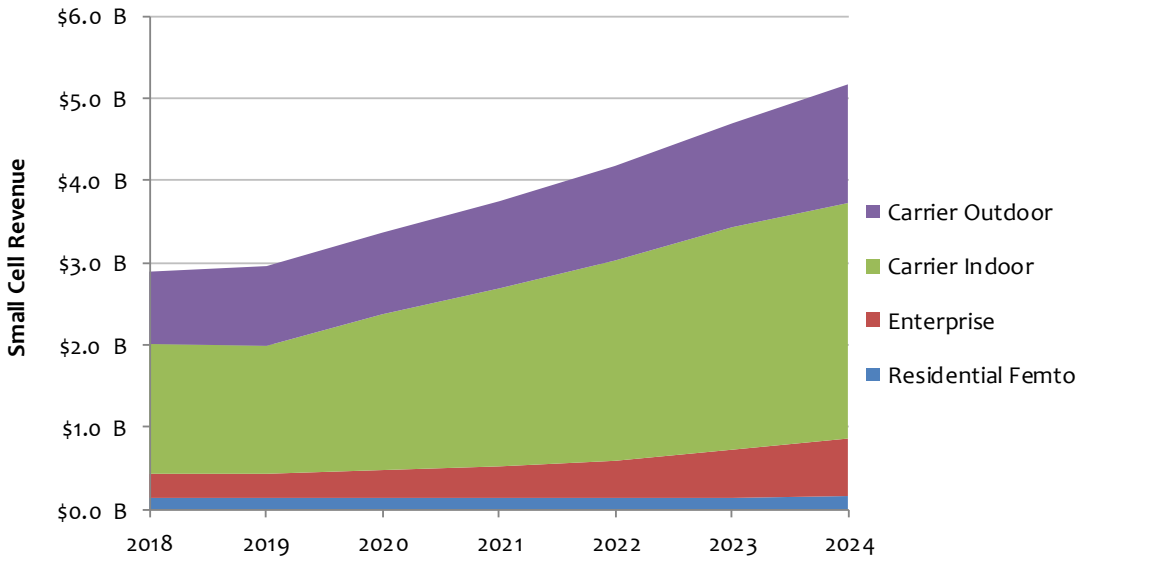
Source: Mobile Experts

Chart 12: Small Cell Revenue Share, by Product Type, 2018

While the Carrier Indoor segment is forecasted to represent the largest market opportunity, rising from $1.6B in 2018 to $2.9B in 2024, the Enterprise segment is expected to grow at a faster rate at 15% CAGR from 2018 to 2024. One of the main reasons for the faster enterprise growth is based on our current assumption that Private LTE and 5G applications by industries will lead to a faster ramp up after 3GPP Release 16 products targeting low-latency and deterministic features of 5G will be adopted in many industrial automation applications in Manufacturing, Transportation, and other industry verticals. Meanwhile, the Carrier Indoor segment is forecasted to grow at 10% CAGR despite being the largest base of small cell deployments today. Despite the lower unit volume, the Carrier Outdoor segment is expected to see a healthy 8% CAGR growth during our forecast period as the higher average selling price of outdoor units – especially much higher-priced Hi-Power Carrier Outdoor small cells -- will make up for the lower growth rate in unit shipments.

Meanwhile, the Residential femtocell segment will see modest revenue growth from $140M in 2018 to $160M in 2024. While femtocells represent about 40% of all small cells shipped today, the revenue market opportunity is very small. With average selling price less than $100, it is very difficult for femtocell vendors to squeeze out meaningful margins to sustain on-going operations. Not surprisingly, major infrastructure vendors like Ericsson, Huawei, and Nokia mostly focus on high-performance Carrier Outdoor and Indoor segments and sometimes outsource femtocell development to ODM partners. Meanwhile, small cell specialists like Airspan and Parallel Wireless have been able to address niche segments, focusing onoperator pain points. For example, Airspan's wireless relay and strand-mount small cells have been critical in addressing siting challenges for Sprint to quickly deploy network capacity where needed. Meanwhile, Parallel Wireless has

been successfully addressing Hi-Power Carrier Outdoor small cells to expand network coverage and capacity at lower cost.

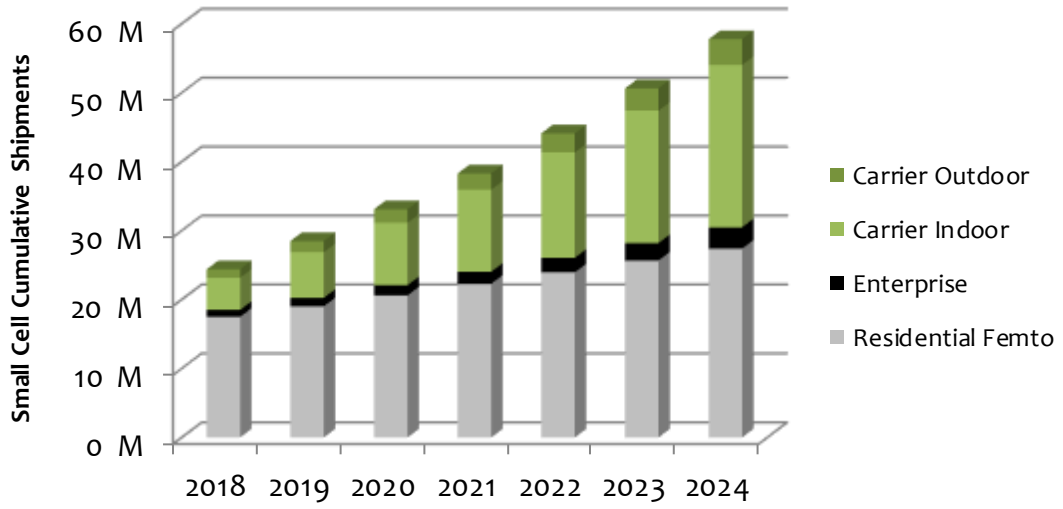


Source: Mobile Experts

Chart 13: Small Cell Revenue Forecast, 2018-2024

Small Cell Installed Base Forecast

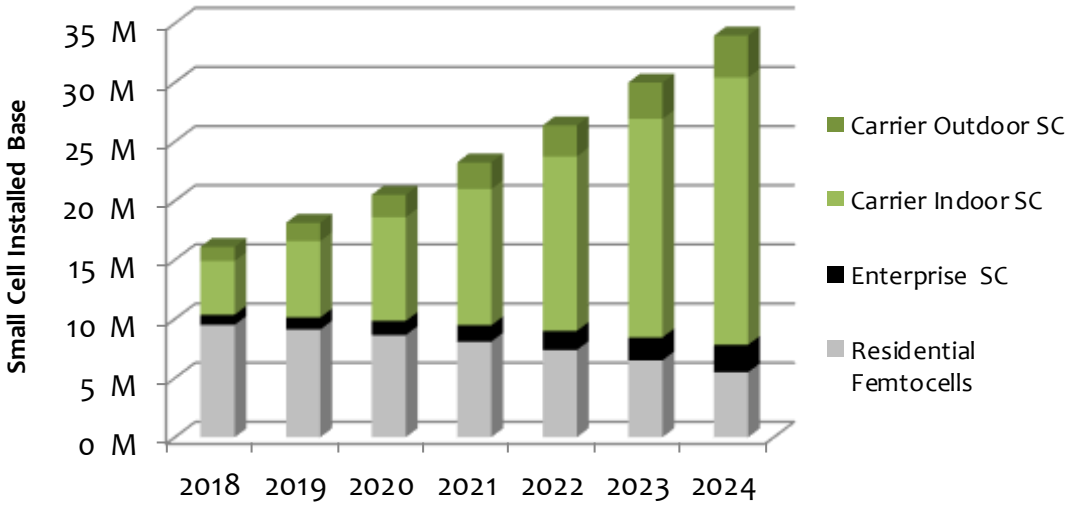
More than 24 million small cells have been shipped to date, and about 16 million units are in service. Mobile Experts tracks the shipments in terms of "Cumulative Shipments" (i.e., the total number of small cells sold to customers) and the "Installed Base" (i.e., the number of units that remain in the field).



Source: Mobile Experts

Chart 14: Small Cell Cumulative Shipments, 2018-2024

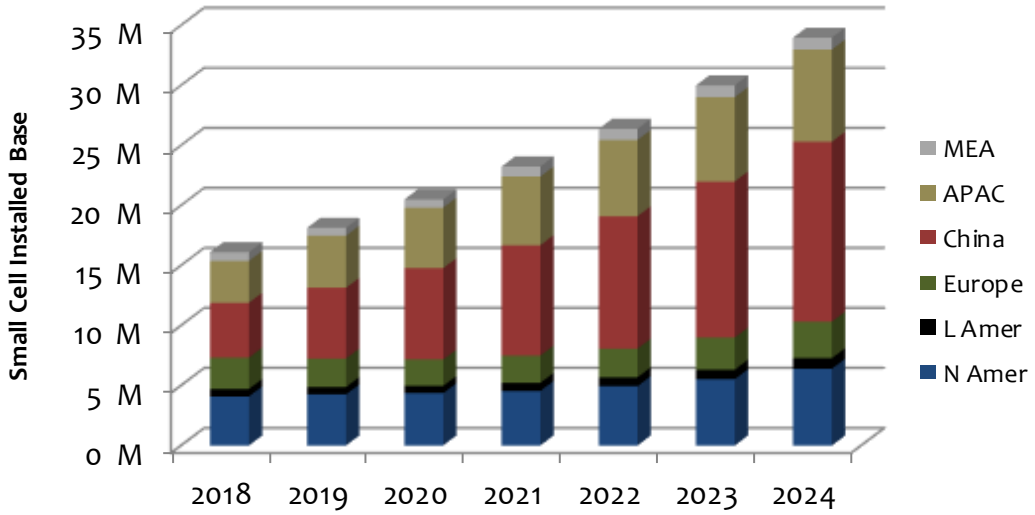
Mobile Experts projects that there is a significant percentage of residential femtocells that are turned off because the end user does not see the meaningful benefit, or simply have turned on after moving. Hence, our model estimates that the installed base of Residential Femtocells declines over time.



Source: Mobile Experts

Chart 15: Small Cell Installed Base, 2018-2024

While North America and Europe represented regions with a large installed base in the early days of small cells largely dominated by Residential Femtocells, the installed base of Small Cells has largely shifted to China and APAC as the operators in those regions have significantly boosted small cell deployments especially Carrier Indoor small cells. For example, the DRS deployments (e.g., Huawei LampSite) in China has been big and continues to grow. Moreover, Jio in India has jump-started the small cell deployments in India and competitors have increased their small cell deployments as well. Meanwhile, Korea and Japan continue to see steady growth of residential femtocells and low-power RRHs to fill-in coverage "holes" and expand capacity where needed.



Source: Mobile Experts

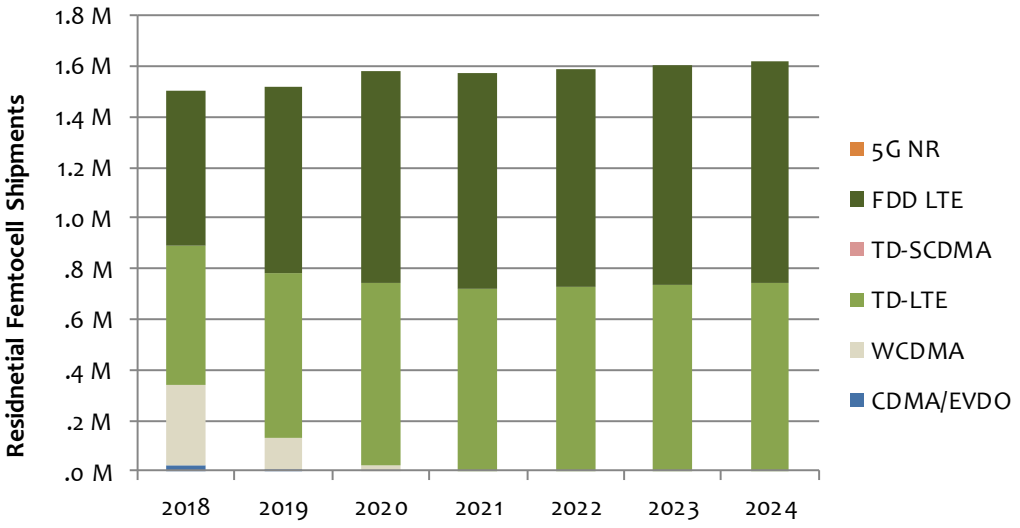
Chart 16: Small Cell Installed Base, 2018-2024

Residential Femtocells Forecast

Residential femtocells reached a peak about four years ago when residential femtocells were seen as a quick and inexpensive way to address network coverage and capacity needs. However, the residential femtocell issue brought new challenges for operators to address macro-femtocell handoff and co-channel interference issues. While much of this has been worked out on mature products, residential femtocells are strategically leveraged by the operators to minimize the possible implication on their core Macro networks. Cost consideration remains a key driver, as mobile operators no longer view subsidization of residential femtocells as only means to extend mobile coverage indoors. Voice over Wi-Fi (VoWiFi) and other alternatives like repeaters are viewed as viable options especially as some operators look to extend millimeter wave coverage indoors.

Although the growth has stalled, the residential femtocell market is expected to steadily ship around 1.6 million units annually worldwide. With the high penetration of LTE

networks in most major regions, we see LTE dominating the residential femtocells. While we still see dual-mode WCDMA /LTE femtocell shipments, we expect to see single-mode LTE femtocells to dominate as more operators run both voice and data traffic over LTE. A key "wild card" in our forecast is whether cable operators in the USA would adopt an "inside out" strategy whereby residential femtocells or broadband gateways are used for mobile network services. While there is a longer-term probability that they may adopt this strategy, we believe that residential femtocell use will be limited in the near term. We believe they will adopt the traditional "outside-in" approach via strand-mount CBRS small cells for example before taking the risky femtocell strategy – which requires a fairly significant CAPEX on customer premise equipment.



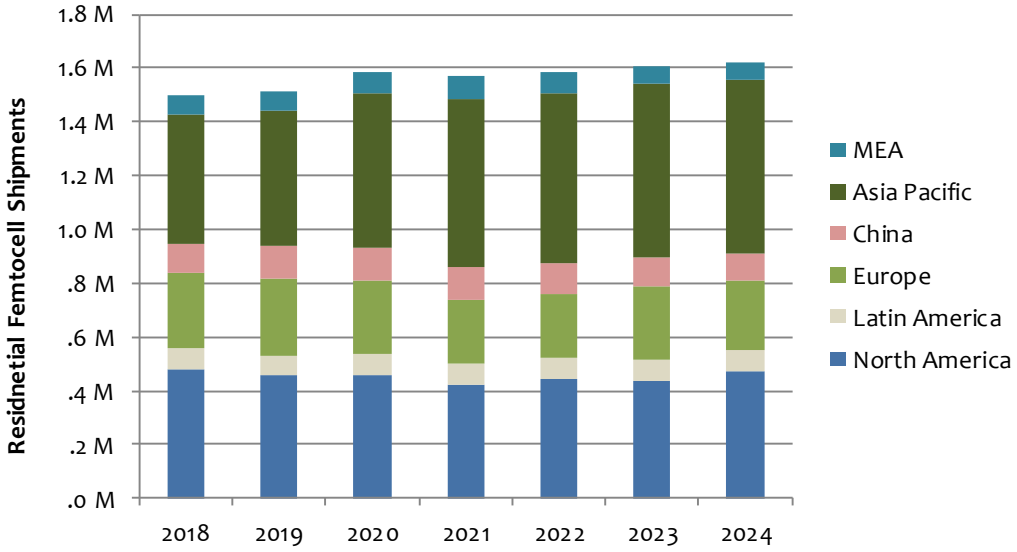
Source: Mobile Experts

Chart 17: Residential Femtocell Shipment Forecast, by Air Interface, 2018-2024

The residential femtocell market is largely led by North America, APAC, and Europe. In North America, Tier 1 operators like T-Mobile, Sprint, and Verizon have actively deployed dual-mode and single-mode LTE femtocells to extend mobile coverage indoors in the residential and SOHO/enterprise market segments. In APAC, we have observed a steady pace of LTE femtocell deployments in developed markets such as Japan. Meanwhile, Indian operators, Airtel and Vodafone-Idea appear more interested in the utilization of femtocells to combat Jio's rapid market share gains. With the three carriers having roughly similar market share in terms of revenue, we expect Vodafone and Airtel to mimic some of Jio's network "playbook" in terms of leveraging lower-cost infrastructure options like small cells to increase network capacity and coverage.

In last year's report, we had speculated that certain spectrum-constrained operators to leverage LAA in certain indoor and outdoor scenarios to harness unlicensed spectrum to provide higher "Gigabit LTE" speed services and selectively add network capacity in hotspot locations. We had projected that the possibility of LAA in residential femtocells

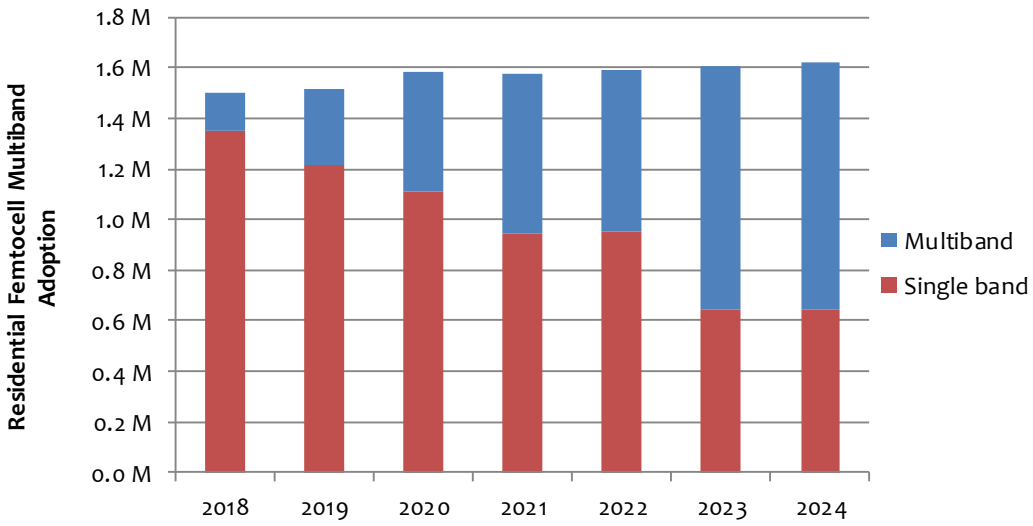
would be limited due to higher CAPEX cost. Our projection appears to be correct. We have not seen LAA support in residential femtocells even though we have seen LAA deployment in Carrier Indoor small cells. Our forecast now assumes that LAA won't be supported in Residential Femtocells.



Source: Mobile Experts

Chart 18: Residential Femtocell Shipment Forecast, by Region, 2018-2024

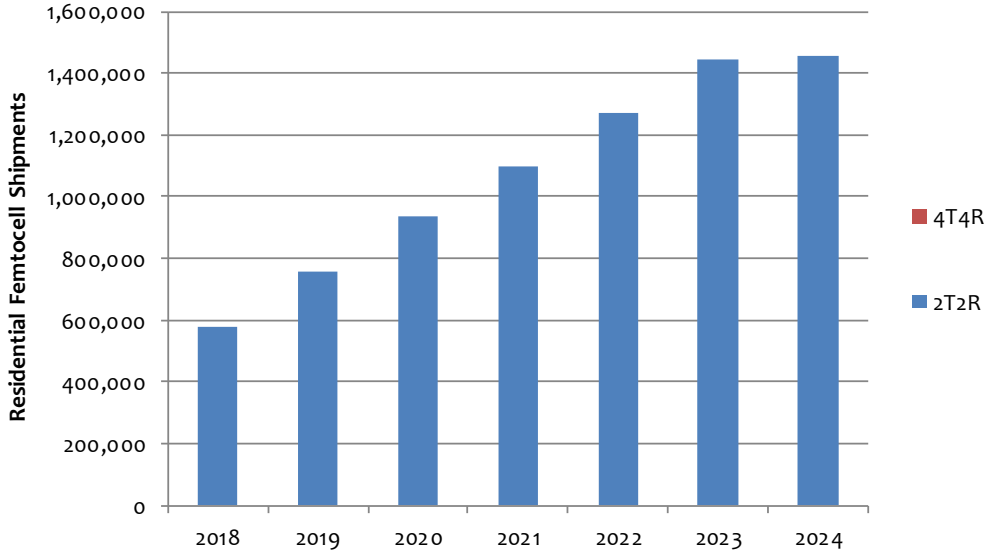
Residential femtocells are becoming more powerful with increased LTE capacity, with some SOHO-targeted units handling up to 64 users with 3G/LTE dual-band support. While the majority of residential femtocells shipped today are single-band devices, we expect an increasing number of new residential femtocells to support multiband carriers with two RF carriers for 3G + LTE configuration or two LTE carriers to possibly take advantage of carrier aggregation.



Source: Mobile Experts

Chart 19: Residential Femtocell Shipment Forecast, by Multiband Type, 2018-2024

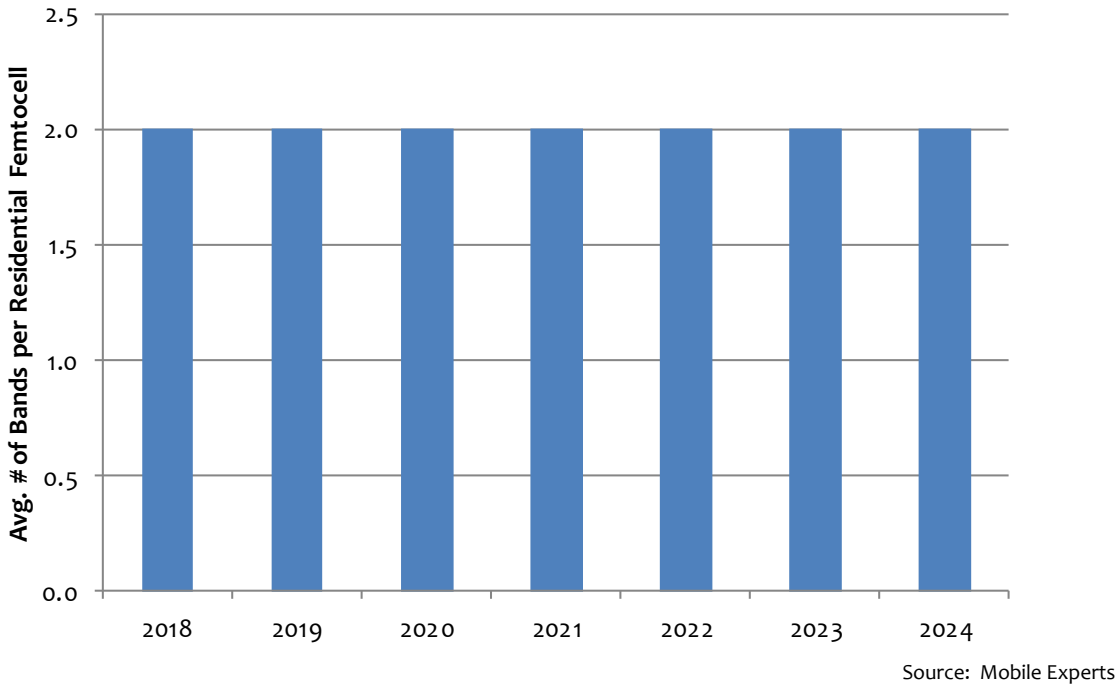
During our forecast period, we expect an increasing number of residential femtocells to support two RF carrier (2T2R) configuration with an internal omnidirectional antenna for easy self-install. With cost constrained on bill-of-materials (BOM), we do not expect residential femtocells to adopt higher RF carrier configurations such as 4T4R, which will be more common for higher-priced carrier-grade units for outdoor and enterprise indoor units.



Source: Mobile Experts

Chart 20: Residential Femtocell Shipment Forecast, by Antenna Configuration, 2018-2024

With our revised view that LAA adoption in Residential Femtocells won't materialize, we expect the average number of bands per residential units to be around two. We don't expect this figure to increase as the possibility of carrier aggregation with LAA for example probably won't happen on these low-cost radios.



Source: Mobile Experts

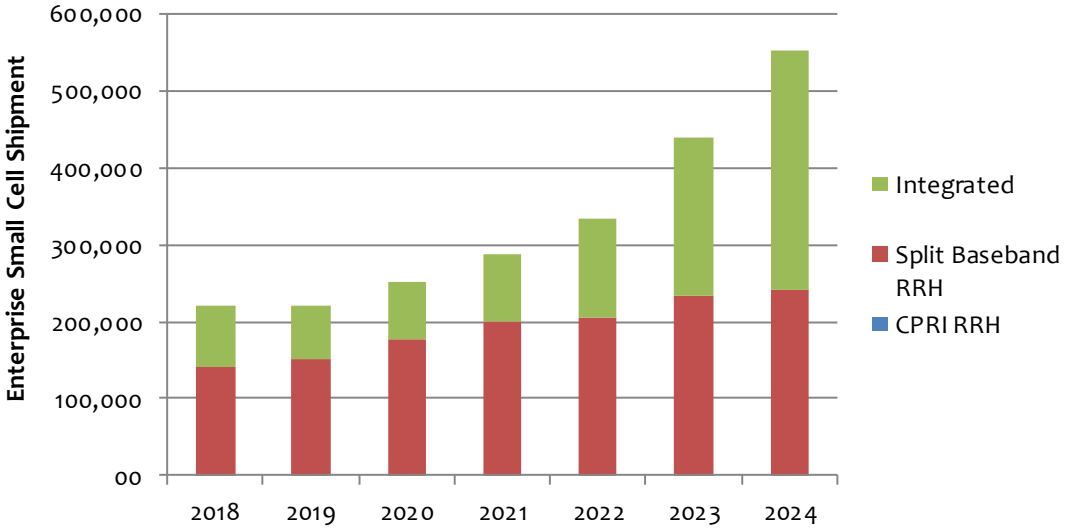
Chart 21: Avg. # of Bands per Residential Femtocell Unit, 2018-2024

Enterprise Small Cells Forecast

The Enterprise small cell market has maintained fairly steady growth over the past several years even though a "direct-to-enterprise" business model has not materialized. Some of the growth has come from system integrators seeking to address in-building wireless projects with solutions beyond DAS. As the CBRS market develops over the next few years, we anticipate the Enterprise small cell market to ramp up as Private LTE applications on the CBRS band ramps up in 2020. As the CBRS market matures and we see a growing list of handsets that support the band come to market, the traditional in-building wireless for mobility services will drive the market further. Outside of traditional in-building wireless and mobility services, industrial applications on dedicated C-band spectrum – e.g., 3.7 – 3.8 GHz band in Germany – will drive further growth of Enterprise small cells for private enterprise applications.

Enterprise small cells are mostly integrated units with baseband and radio functions housed in a common enclosure for quick and easy installation by IT folks. Small cells need to look and connect like Wi-Fi access points which are well known to IT staff. Popular Enterprise small cells like Spidercloud/Corning use controller-based architectures to

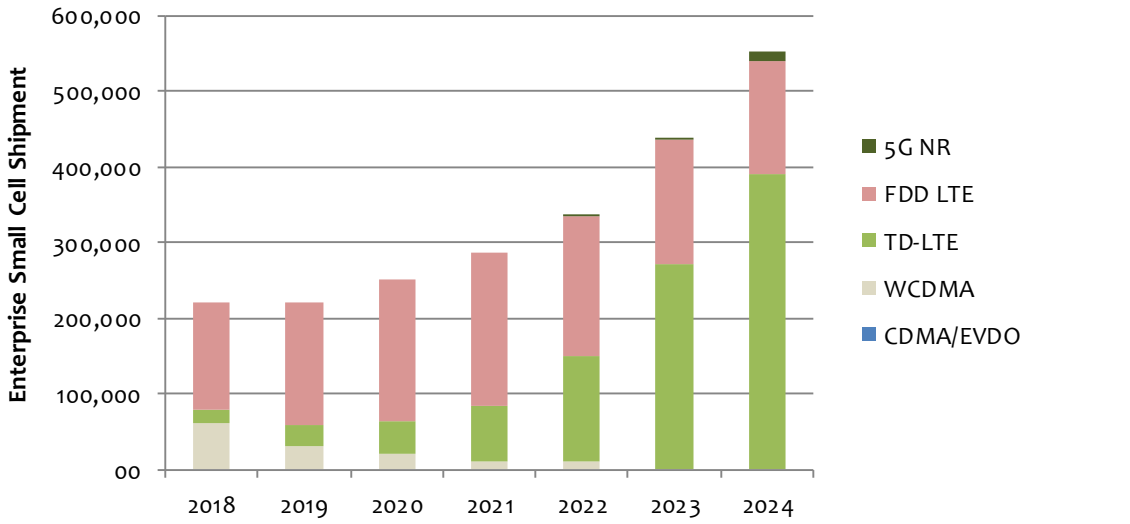
coordinate multiple radio units inside a building so that they don't interfere with macro dominance or handoff issues. This type of split-baseband RRH architecture where baseband and certain portions of Layer 1-3 functions are centralized--while lower-layer radio functions are distributed--is commonly leveraged in in-building wireless mobility applications. On the other hand, we expect Enterprise units used primarily for private LTE applications in the outer years will be mostly integrated units since the LTE-TDD spectrum deployed for those applications will be mostly dedicated for the private wireless applications and do not need to contend with macro handoff issues.



Source: Mobile Experts

Chart 22: Enterprise Small Cell Shipment Forecast, by Fronthaul/Backhaul, 2018-2024

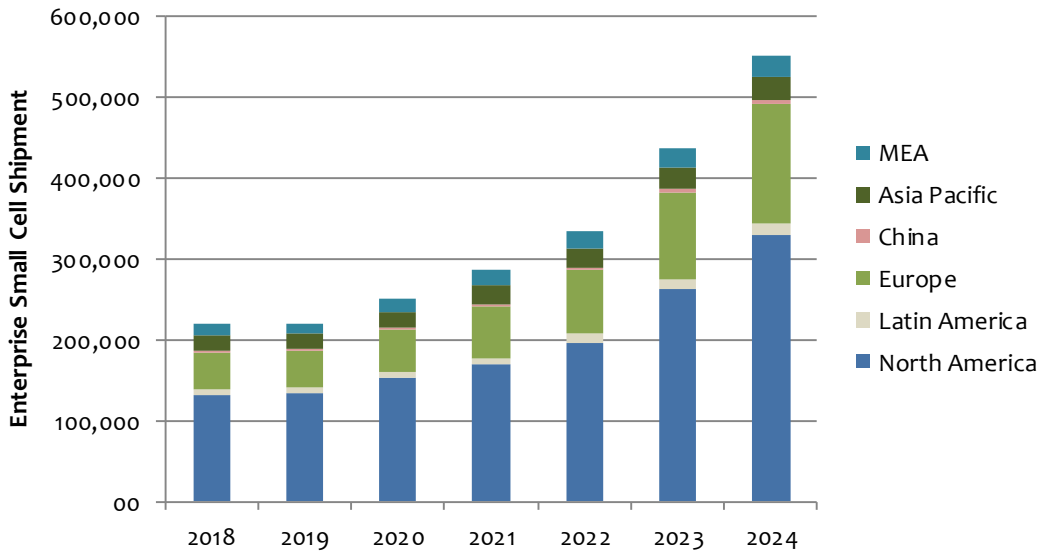
The Enterprise small cell adoption is largely confined in North America and Europe -- due to a large number of enterprises based in those regions and the free-wheeling business culture in key countries. With dominant enterprise applications that center around mobile voice applications, WCDMA and FDD LTE are common technologies supported on Enterprise small cells today. As small cell deployments increasingly leverage TD-LTE bands in the 2.5 GHz and CBRS bands in the USA, and TDD bands in the C-band globally, TD-LTE will take an increasing share of Enterprise small cells. We expect the majority of Enterprise small cells in the future to come from 3.5 GHz CBRS in the USA and private LTE and 5G applications for industrial automation to ramp up starting 2022. Starting in 2023, we forecast a very small portion of Enterprise small cells to leverage 5G NR to take advantage of ultra low-latency features in the 3GPP Release 16 standards.



Source: Mobile Experts

Chart 23: Enterprise Small Cell Shipment Forecast, by Air Interface, 2018-2024

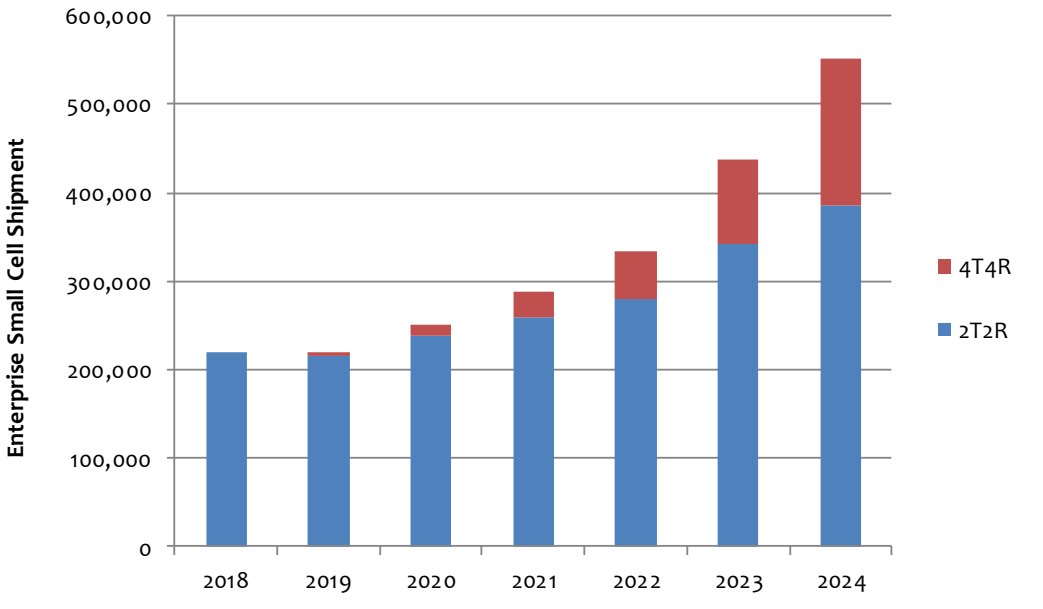
The North American and European regions will lead the Enterprise small cell market segment as enterprise-led IT/telecom infrastructure investments are considered market norms there. As such, the operators in those regions tend to refrain from direct funding of in-building wireless projects beyond marquee public venues like stadiums and airports. Managed service providers and system integrators typically step forward in smaller in-building wireless projects. Here, the system integrators leverage a wide variety of solutions ranging from DAS, small cells, and repeaters to address the market needs. As the CBRS ecosystem matures, and the CBRS Alliance push to drive the adoption of CBRS small cells in the marketplace, we expect strong growth for Enterprise small cell especially as enterprises look to LTE-based systems on "new" spectrum such as CBRS or C-band in Europe to help facilitate industrial-grade wireless networking needs in critical automation use cases such as factory automation.



Source: Mobile Experts

Chart 24: Enterprise Small Cell Shipment Forecast, by Region, 2018-2024

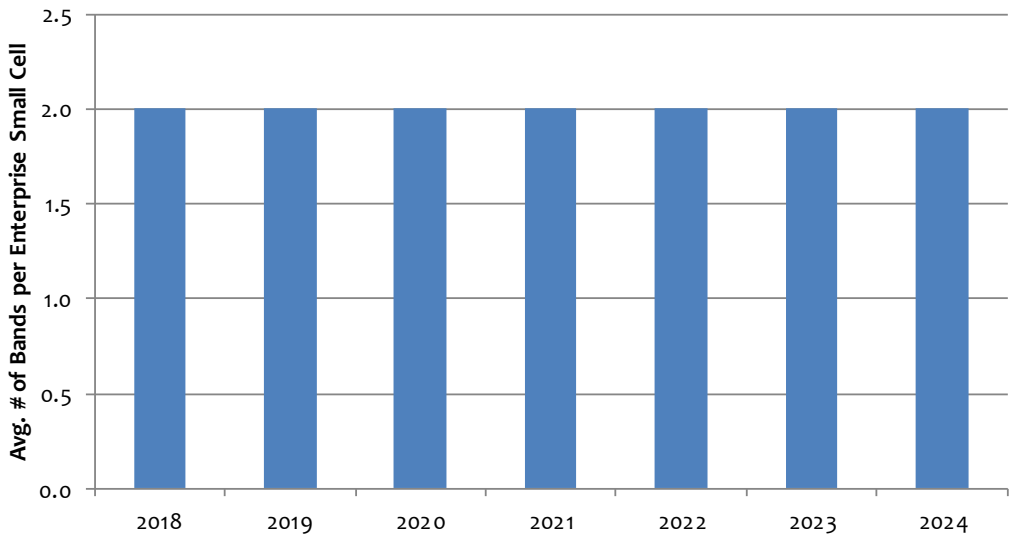
Similar to Residential femtocells, most Enterprise small cells support two RF carrier (2T2R) configuration with an internal omnidirectional antenna for easy self-install. We expect some Enterprise small cell units to support 4T4R configuration to take advantage of carrier aggregation. Enterprises will need to support high peak data rates in hundreds of Mbps to keep up-to-date with Wi-Fi speeds.



Source: Mobile Experts

Chart 25: Enterprise Small Cell Shipment Forecast, by Antenna Configuration, 2018-2024

A majority of Enterprise small cells today support dual-carriers. As operators add additional carriers to take advantage of carrier aggregation for higher capacity throughput, both integrated and RRH variants need to support additional carriers.

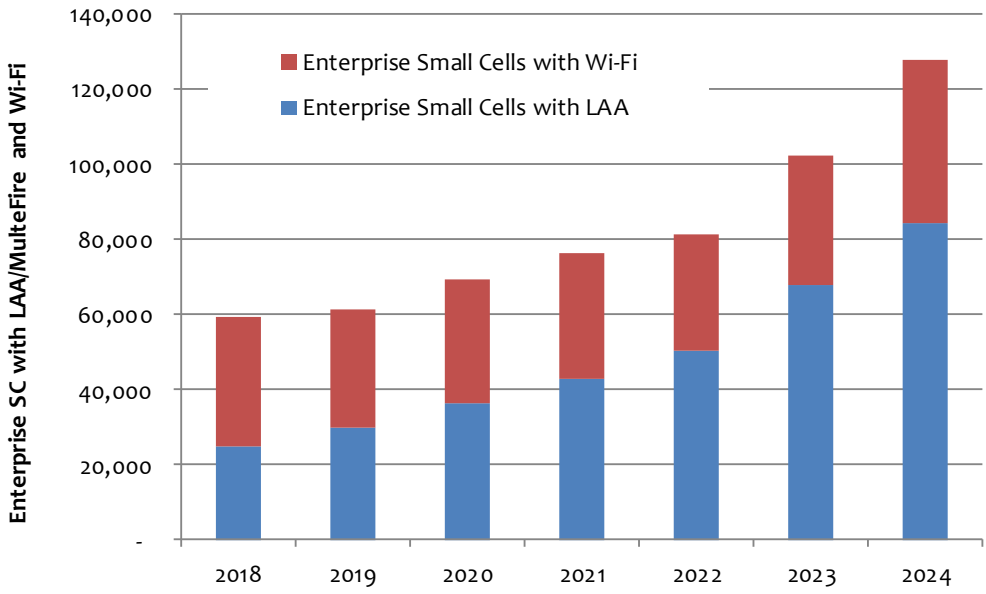


Source: Mobile Experts

Chart 26: Avg. # of Bands per Enterprise Small Cell Unit, 2018-2024

Our view of Wi-Fi integrated Enterprise small cells has changed pretty significantly over the past year. While we believe Wi-Fi integration can be easily accomplished through chipset-level integration, we have not seen small cell vendors widely adopting Wi-Fi integrated small cells. We had seen roadmaps in the past, but in reality, it appears that there isn't much demand for such products. While the physical integration of Wi-Fi on Enterprise small cells is certainly feasible, it appears that network design and deployment of Wi-Fi network is viewed differently or separately from LTE network design. We now anticipate less than 10% of Enterprise small cells to include Wi-Fi connectivity integrated into the small cell products.

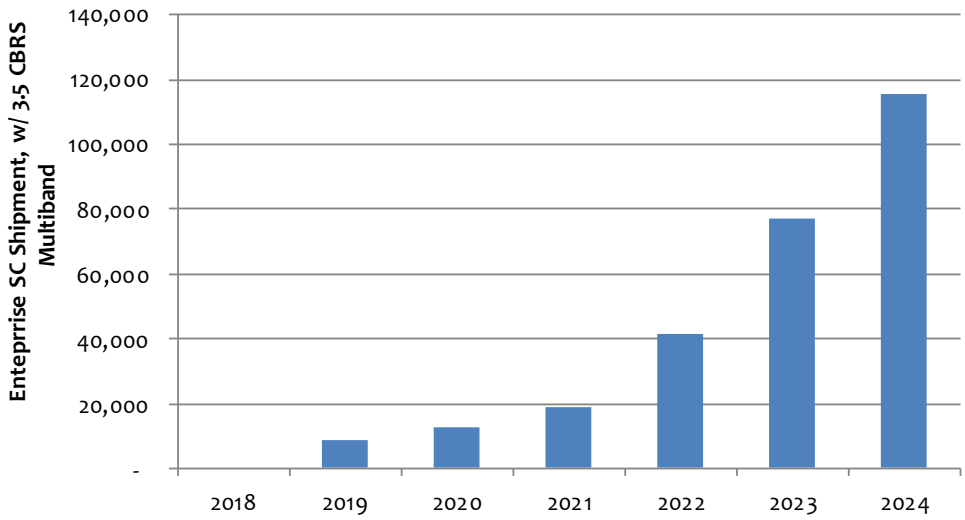
During the same period, Mobile Experts believes that LAA/MulteFire adoption to be scant as the enterprise value proposition of adopting LAA is not very clear. Many enterprises have Wi-Fi deployed and may be wary of deploying LTE in the unlicensed 5 GHz band due to perceived interference concerns. As operators deploy additional spectrum bands to increase network capacity with LAA or CBRS possibly, Enterprise small cells will need to support a higher number of multiband carriers. Enterprise-targeted LAA and CBRS small cells will likely need dual-carriers with 2 x 200 mW (licensed sub-3 GHz) or 2 x 400 mW (for LAA) to compensate for different propagations at the different spectrum bands.



Source: Mobile Experts

Chart 27: Enterprise Small Cell Shipment Forecast, with LAA and Wi-Fi, 2018-2024

While the prospect of leveraging CBRS networks for neutral host in-building wireless service has been discussed for the past few years, we believe the ecosystem of devices and operator support has not reached a critical mass. We see a growing list of CBRS-enabled smartphones coming to the marketplace (e.g., Samsung Galaxy S10, Pixel 3, and others in the pipeline), but the business case necessary for operators' full support has not materialized yet. Despite these challenges, we forecast about 35% of Enterprise small cells shipped in North America will be capable of supporting CBRS in 2024 as private LTE applications will drive the ecosystem in the near term. The CBRS commercialization is now expected to commence in the third or fourth quarter of this year as FCC, NTIA, and DoD give their approval after many years of SAS and ESC testing.



Source: Mobile Experts

Chart 28: Enterprise Small Cell Shipment Forecast, with 3.5 GHz CBRS, 2017-2023

Carrier Indoor Small Cells Forecast

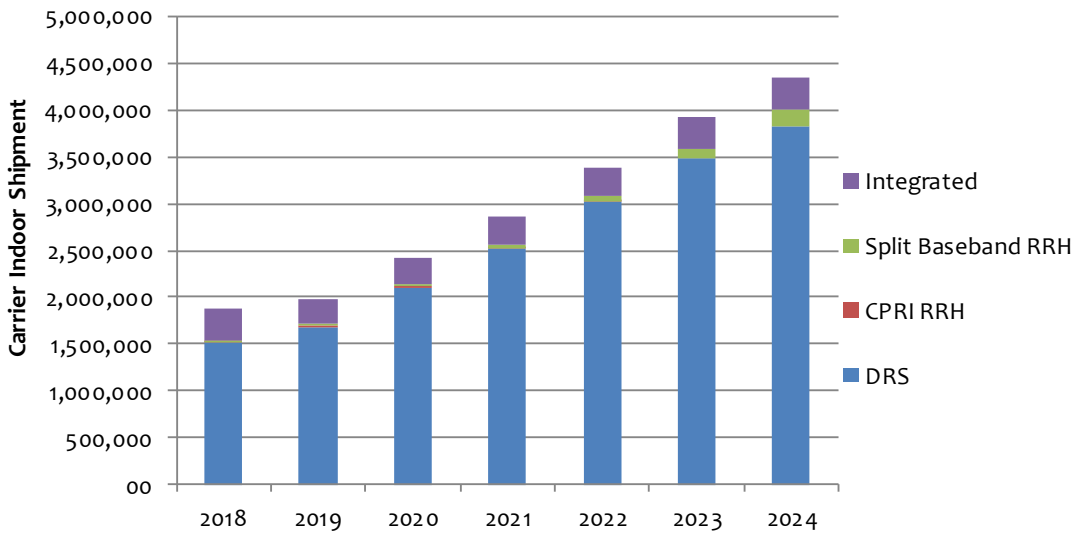
Reminiscent of the early days of the Small Cells industry, driven by residential femtocells, the market is now clearly driven by high-performance Carrier Indoor small cells especially C-RAN based DRS radios that further extend operator macro coverage deep inside buildings. As a part of its indoor digitalization strategy, the Chinese operators have been especially aggressive in indoor small cell deployments with DRS radio units such as Huawei Lampsite and ZTE Qcell. As operators seek answers to the rising traffic growth, indoor small cell deployments have become more pronounced in the past couple of years. Overall Carrier Indoor unit shipments across the different DRS/RRH/Integrated categories grew over 55% year over year in 2018. While we expect this torrid pace of Carrier Indoor small cell deployments to subside this year as operators transition to 5G, the strong momentum of Carrier Indoor small cell deployments is likely to continue. We forecast the Carrier Indoor small cell unit shipment to grow at 15% CAGR from 2018 to 2024.

With a strong push by the Chinese operators, all major vendors have announced 5G DRS products, including Nokia which has joined the DRS bandwagon last year. Under the Digital Indoor System (DIS) banner, Huawei, Ericsson, Nokia, and ZTE have all announced 5G DRS products. Also, some tier 1 operators are encouraging other vendors to bring new solutions to the market under the O-RAN initiative. The DRS architecture has been extremely popular as the DAS-like flexibility in spectrum band deployment, and centralized baseband pooling has allowed operators to optimize RF design and resource deployment for specific venue types. In 2018, DRS unit shipments reached over 1.5M units, making up over 80% of all Carrier Indoor small cell unit shipments. Mobile Experts anticipates continued growth of this architecture mostly in China.

In addition to DRS, the Wireless Relay small cells like Airspan's Magic Box and Huawei

Libero provided strong volume contribution in this category in 2018. Note that these Wireless Relay small cells are categorized as "Integrated" in our forecast. By combining LTE CPE and eNodeB base station functionalities, these Wireless Relay small cells offer a flexible alternative to traditional small cell deployments requiring wireline backhaul, and provide cost-effective means to surgically extend coverage, and more importantly capacity, where needed. Unlike repeaters, these units contain actual baseband processing; thus, they do not merely repeat macro signal, and possibly interfering noise, which can be troublesome in network performance, not just in indoor networks but macro layer as well.

With the revision to how we define Small Cells – i.e., excluding millimeter wave radio units, our forecast of Integrated Carrier Indoor small cells has been significantly reduced from our forecast last year. We had projected that significant millimeter wave indoor deployments will be driven by the "all-in-one" integrated 5G millimeter wave radio units. Now that 5G millimeter wave is now covered in our separate report, we expect Carrier Indoor integrated units will be meaningfully less going forward. With all major vendors now adopting the DRS architecture for carrier-grade indoor deployments in China – which drives the global market in this category – this segment will be primarily driven by DRS radio units and some O-RAN vendor products supporting O-RAN defined split-baseband RRH architecture.

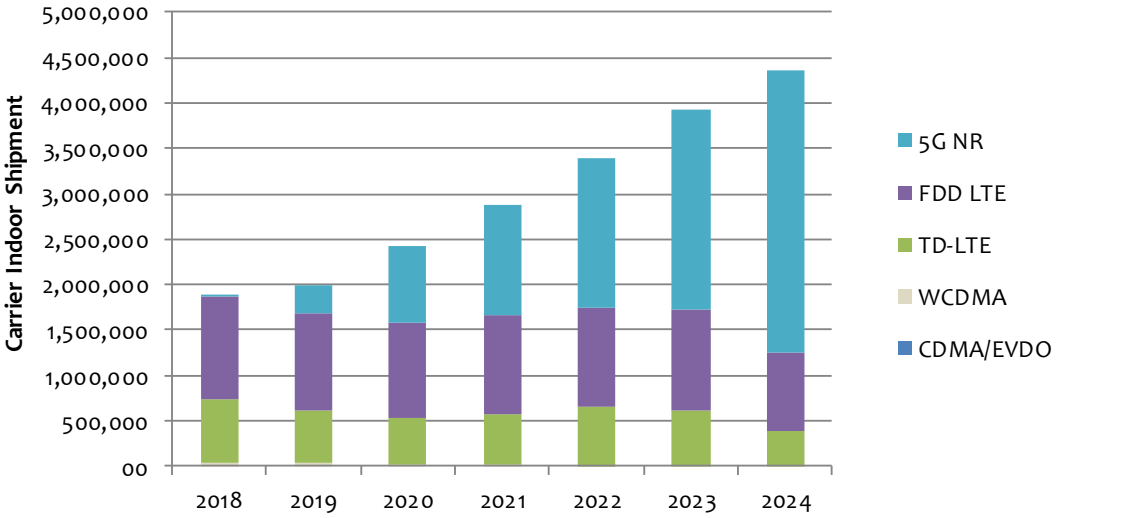


Source: Mobile Experts

Chart 29: Carrier Indoor Small Cell Shipment Forecast, by Fronthaul/Backhaul, 2018-2024

With the strong growth of Carrier Indoor deployments in China and APAC in the past couple of years, TD-LTE dominates the landscape for Carrier Indoor small cells in the near term. With small cell SoC chipset implementations supporting both FDD and TDD LTE operations, the incremental cost to support both operations is minimal, and we expect Carrier small cell shipments to support multimode operations. With all major vendors

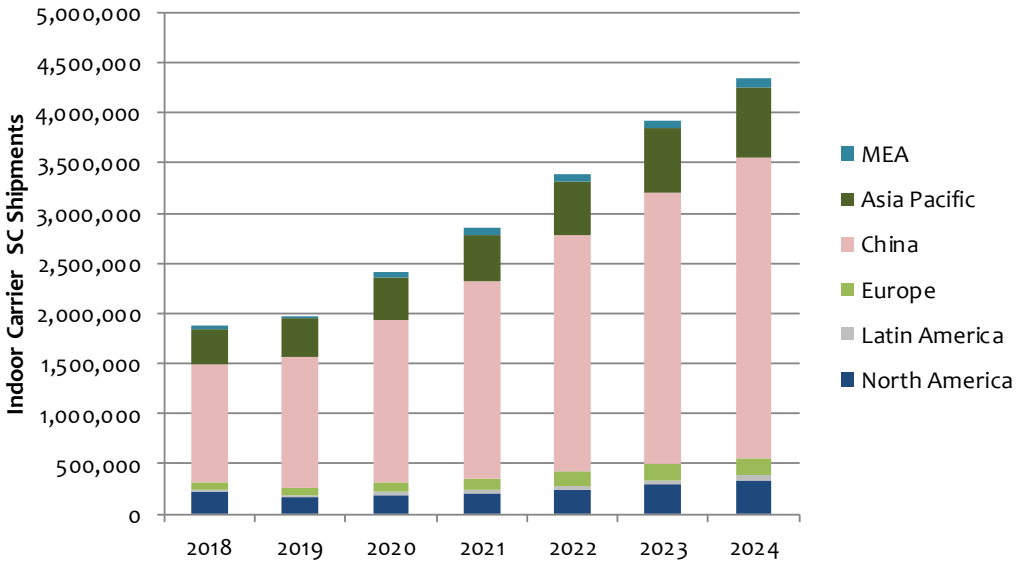
introducing dual-mode LTE/5G and standalone 5G DRS radio units in the second half of 2019, we expect a small portion of DRS deployments in China to support 5G as the Chinese operators gear up for widescale 5G deployments in 2020.



Source: Mobile Experts

Chart 30: Carrier Indoor Small Cell Shipment Forecast, by Air Interface, 2018-2024

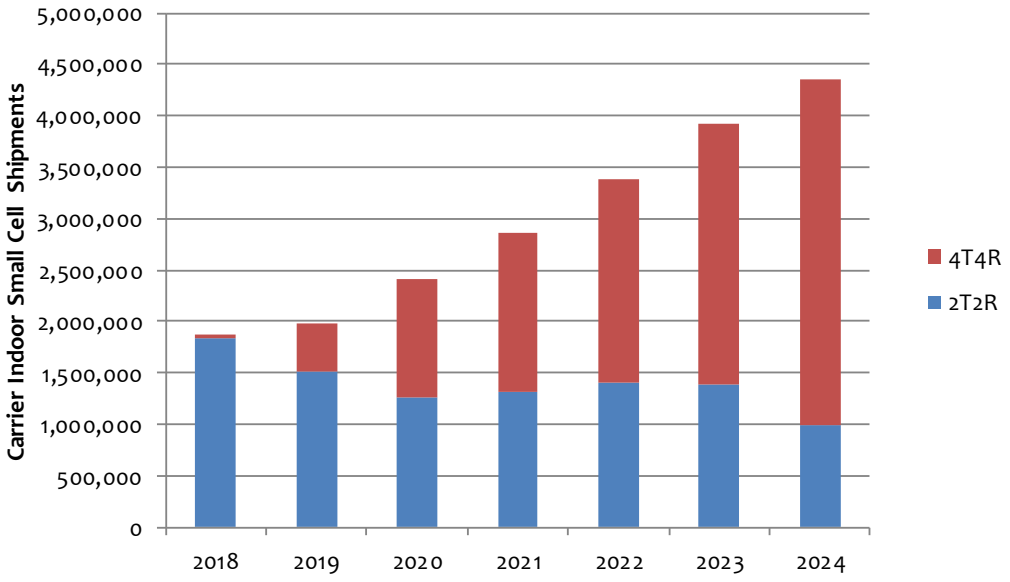
The China and APAC regions dominate the Carrier Indoor small cell deployments, and this trend is expected to continue as large installed base of DRS systems provide the foundation for future 5G DRS unit upgrades and new deployments. All major tier 1 infrastructure vendors including Ericsson, Huawei, ZTE, and Nokia have all announced 5G DRS radios operating in the C-band to be available in the second half of 2019. Huawei has already completed a 5G DRS trial with China Unicom in the second half of last year. We expect Carrier Indoor deployments to ramp up in APAC as the operators in developed markets in Korea and Japan complement their 5G macro deployments with indoor deployments and Indian operators look to leverage indoor deployments also to expand network capacity as they struggle to keep up with the rapidly rising traffic demand.



Source: Mobile Experts

Chart 31: Carrier Indoor Small Cell Shipment Forecast, by Region, 2018-2024

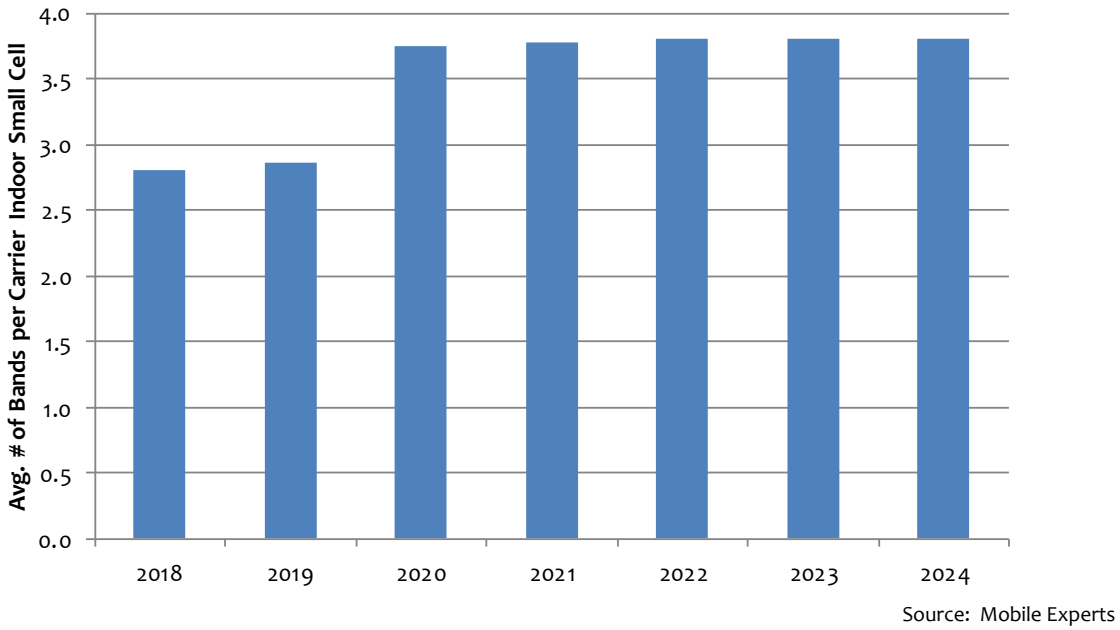
The heavy influence of DRS architecture used in the Carrier Indoor segment directly relates to the wide adoption of multiband support in Carrier Indoor small cells. For example, Huawei's LampSite 2.0 supports three bands, and the next generation LampSite 3.0 can support up to four concurrent bands. At this point, it is fair to assume that all Carrier Indoor small cells are multiband radios.



Source: Mobile Experts

Chart 32: Carrier Indoor Small Cell Shipment Forecast, Antenna Configuration, 2018-2024

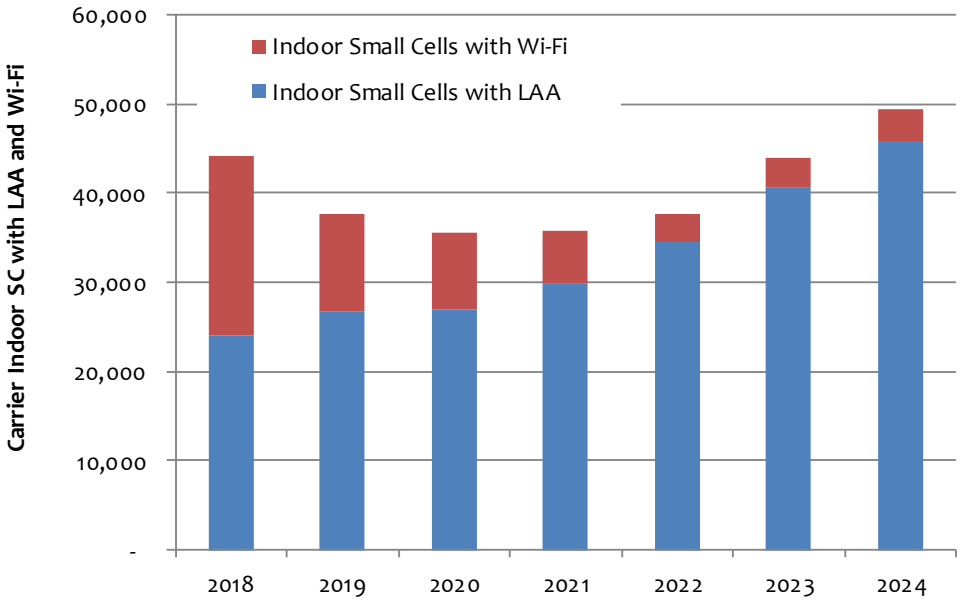
While the majority of Carrier Indoor units have a 2T2R antenna configuration today, we expect the majority of Carrier Indoor small cells to support 4T4R as 5G DRS units are expected to support 4 * 200-250mW. In the handset market, 4x4 MIMO is expected to become a common feature for high-end smartphones over the next few years.



Source: Mobile Experts

Chart 33: Avg. # of Bands per Carrier Indoor Small Cell Unit, 2018-2024

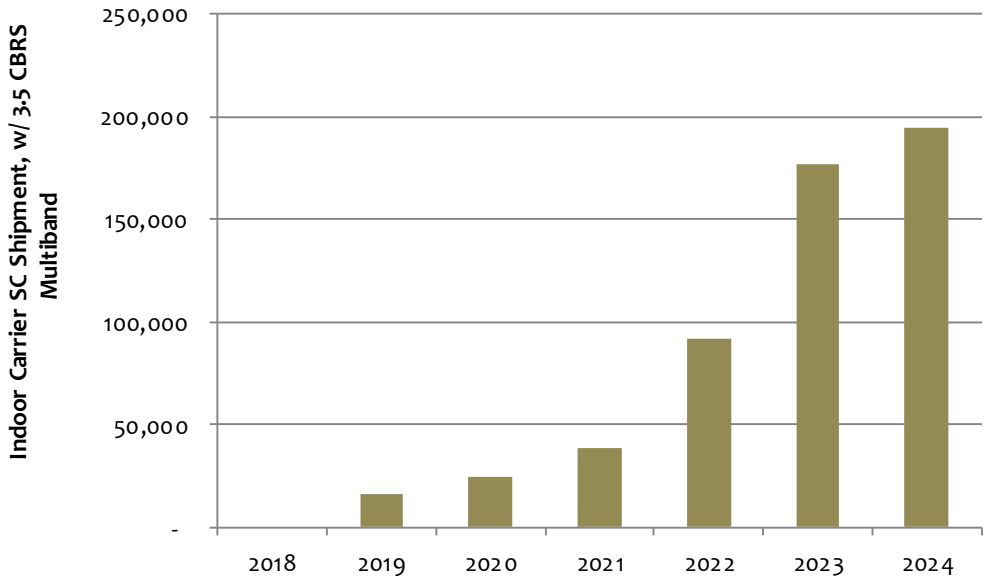
With DRS making up a significant portion of overall Carrier Indoor units, the average number of bands per Carrier Indoor small cell is heavily influenced by the number of bands supported on the leading DRS systems like Huawei's LampSite. LampSite 1.0 began with dual-band support, and the current generation, LampSite 2.0, already supports three bands. Huawei claims that LampSite 3.0 can support four concurrent bands. Overall, the average number of bands per Carrier Indoor unit is expected to hover around 2.8 to 3.8 during our forecast period.



Source: Mobile Experts

Chart 34: Carrier Indoor Small Cell Shipment Forecast, with LAA and Wi-Fi, 2018-2024

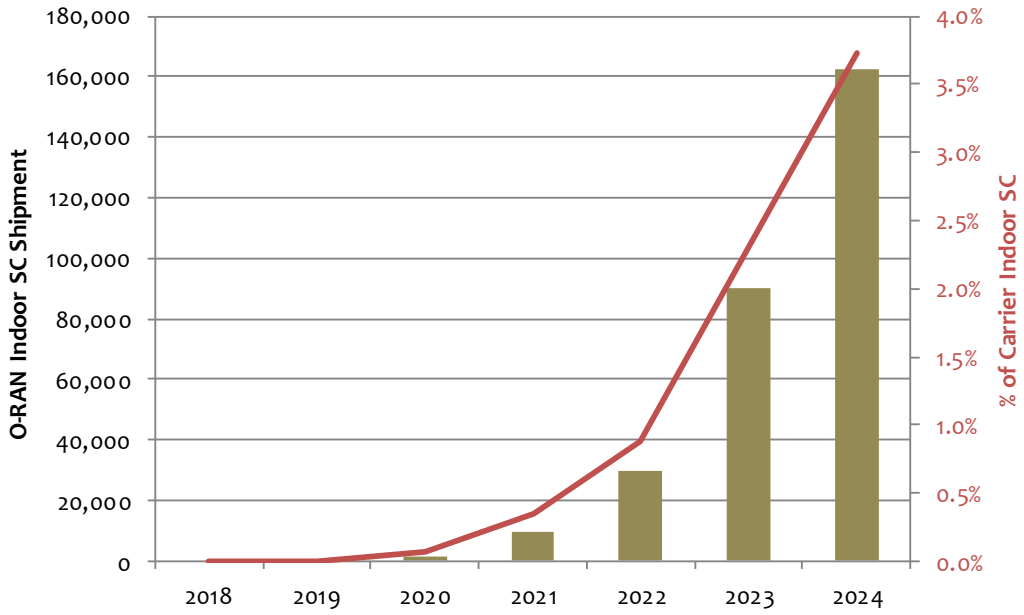
Mobile Experts predicts modest adoption of unlicensed spectrum use in Carrier Indoor small cells. While the number of Carrier Indoor units incorporating Wi-Fi to use the 5 GHz unlicensed spectrum band is expected to ramp down as operators look to LAA for better use of the unlicensed spectrum, Mobile Experts predicts that the LAA ramp-up to be modest as operators evaluate unlicensed spectrum contention issues at many indoor locations. Overall, the combined unlicensed spectrum use through the incorporation of Wi-Fi and LAA on Carrier Indoor units is expected to less than 50,000 units annually. This constitutes less than 2% of total annual Carrier Indoor shipments at the end of our forecast period. The use of the 5 GHz unlicensed spectrum via integrated Wi-Fi module or more directly via LAA will be limited and opportunistic in the long term as Wi-Fi will remain the most cost-effective and "neutral" indoor solution for many enterprise locations.



Source: Mobile Experts

Chart 35: Carrier Indoor Small Cell Forecast, with 3.5 GHz CBRS Multiband, 2018-2024

The U.S. mobile operators' interests in CBRS remain largely focused on outdoor deployment scenarios for fixed wireless access and mobile offload. Our current view of operator deployment of CBRS small cells in indoor context is largely driven from our view that cable operators will be deploying CBRS via integrated Carrier Indoor small cells through their small business channels.



Source: Mobile Experts

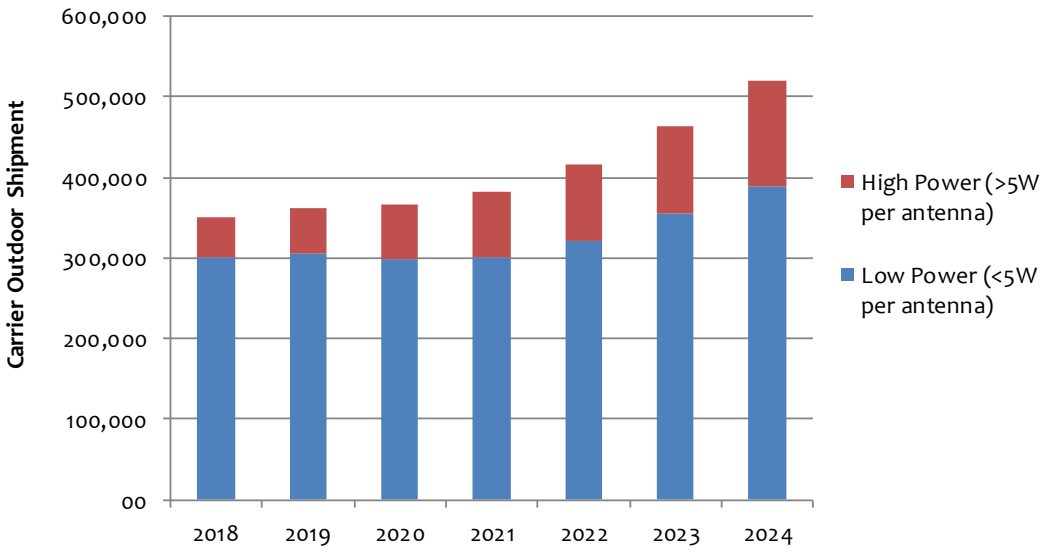
Chart 36: Carrier Indoor O-RAN Small Cell Shipment, 2018-2024

As part of the O-RAN initiative to "open up" RAN architecture and avoid vendor lock-in situation, Mobile Experts believes that some Tier 1 operators will trial O-RAN solutions through limited trials in certain markets and bring opportunity for small cell specialists to compete in the overall RAN market dominated by "gorillas" in the industry (i.e., Huawei, Ericsson, and Nokia). For example, BaiCells is trialing its O-RAN version of DRS system at China Mobile. We expect other operators to follow suit and give other vendors an opportunity to compete for a portion of their RAN capital expenditure. However, we expect this to be very minimal. The total number of O-RAN indoor small cell shipments will only represent less than 4% of all Carrier Indoor shipped units in 2024.

Carrier Outdoor Small Cells Forecast

The Carrier Outdoor small cell segment grew 17% year over year in 2018, largely from continued low-power LTE RRH deployments in Korea, Japan, and North America, pole- and strand-mount small cell deployments in North America, and Hi-Power Carrier Outdoor deployments in select markets. While we generally view Carrier Outdoor deployments to gradually decline over the longer term as major operators focus on massive MIMO deployments on C-band for 5G, the CBRS, and Private LTE markets to drive outdoor small cell deployments by mobile and cable operators alike as they look to expand market opportunities in vertical industries. Over the longer term, we expect the Carrier Outdoor segment to grow at 7% CAGR from 2018 to 2024. Again, as a result of our market focus excluding millimeter wave spectrum deployments on "small cell" infrastructure sites including street-level fixtures like light poles and strand-mounts, this year's Carrier Outdoor small cell forecast is significantly less than our view last year which implicitly included millimeter wave radio units.

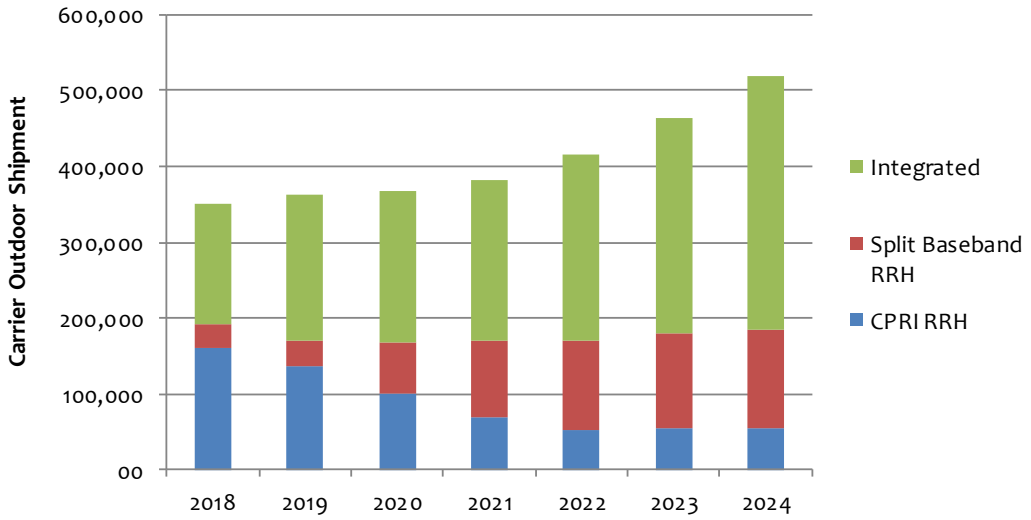
Within the Carrier Outdoor category, we expect the Hi-Power units (e.g., 2x20W radios) to see strong growth as operators with limited coverage and capacity footprints in dense urban and rural areas are increasingly looking towards these cost-effective macro-like small cell radios to add network capacity and expand coverage. By deploying Hi-Power Carrier Outdoor units on rooftops and utility/traffic poles in key right-of-ways, an operator can lower network operating expenses by opting to place "small cell" radios on less expensive "street furniture" rather than traditional macro towers. We expect the Hi-Power Carrier Outdoor small cells to constitute about 14% of total Carrier Outdoor unit volume in 2018, rising to 25% in 2024. For an increasing number of operators, these macro-like Carrier Outdoor small cells are a cost-effective solution to lower both CAPEX and OPEX costs.



Source: Mobile Experts

Chart 37: Carrier Outdoor Small Cell Shipment Forecast, by Power, 2017-2023

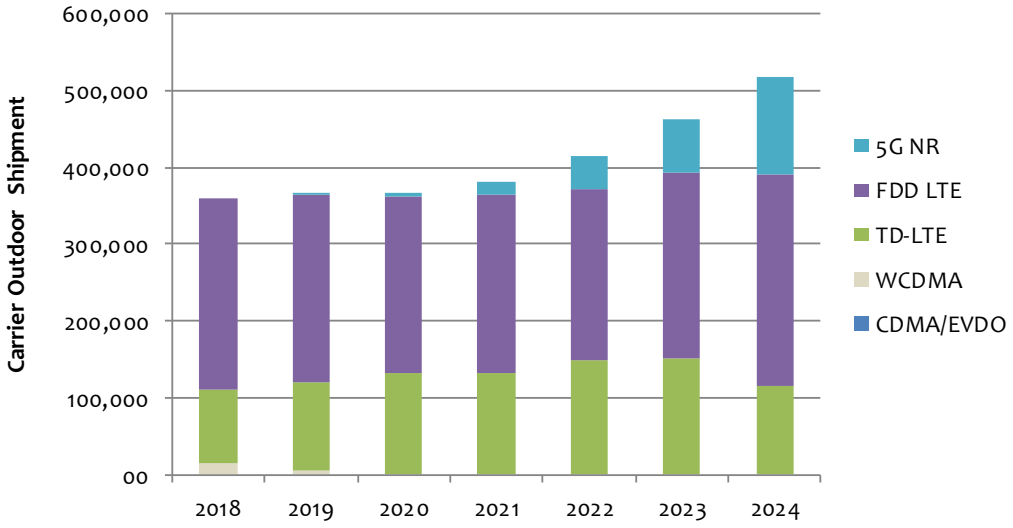
In fiber-rich regions, like China, Japan, and Korea, Carrier outdoor applications will increasingly adopt the C-RAN architecture with low power RRHs to extend mobile coverage and capacity where they are needed. As operators contemplate optimal RAN architecture for 5G services with much higher fronthaul and backhaul bandwidth requirements, Split Baseband RRHs will be more widely deployed as compared to traditional CPRI interface. Meanwhile, "all in one" Integrated outdoor small cell units will be deployed in areas where ease of installation is paramount, and interference with the macro layer is less of an issue. For example, we forecast all Hi-Power Carrier Outdoor small cells in our forecast are integrated units with baseband and radio in one tightly integrated unit. With DRS deployments concentrated in indoor applications, we have removed the DRS category in the outdoor segment this year. Also, we forecast strand-mount small cells to contribute to the growth in the Integrated category of outdoor small cells as operators adopt this deployment strategy to overcome siting challenges of putting them on city infrastructure like street poles. With commercial agreements with cable operators, for example, a mobile operator can access the telecommunications strands to place small cells without the hassle of city-by-city municipality approvals.



Source: Mobile Experts

Chart 38: Carrier Outdoor Small Cell Shipment Forecast, by Front/Backhaul, 2018-2024

As mobile operators densify their LTE networks, FDD and TD-LTE interfaces are expected to dominate air interface technology share for Carrier Outdoor units. Moreover, we are currently forecasting that 5G outdoor units will ramp up starting in 2021 as portions of CBRS radio infrastructure may support dual-mode 5G NR (Non Standalone) and LTE. Our hypothesis is that both mobile and cable operators would be motivated to adopt the latest 5G NR to maximize their network investments to derive the lowest possible "cost per GB" economics.

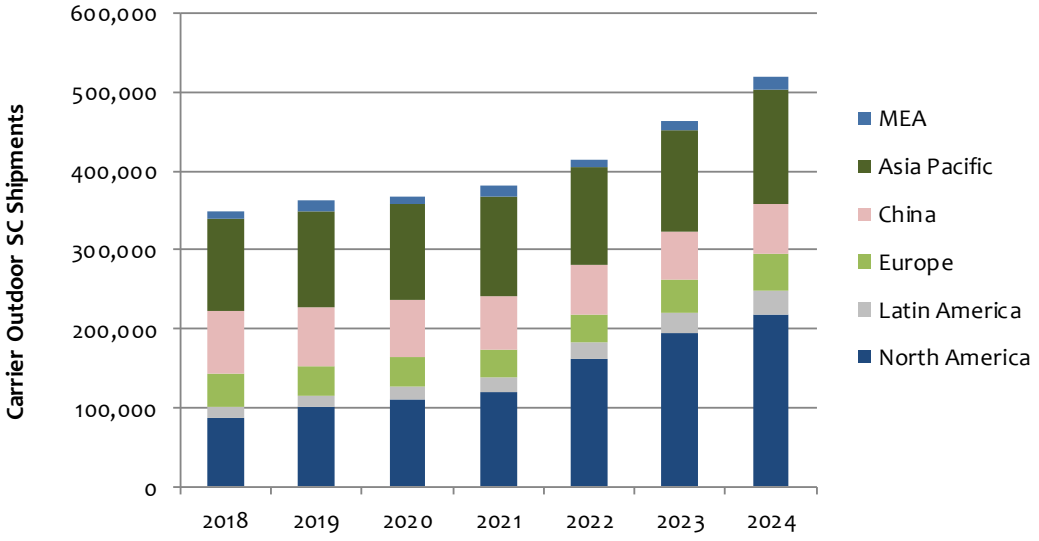


Source: Mobile Experts

Chart 39: Carrier Outdoor Small Cell Shipment Forecast, by Air Interface, 2018-2024

The North American region is forecasted to be the largest market for Carrier Outdoor small cells as the market competition has brought interesting outdoor small cell products to the marketplace. As an "underdog," Sprint has utilized interesting outdoor deployment models including strand-mount and pole-mount outdoor radios to extend and expand its network capabilities over the past several years. While we expect the pending T-Mobile/Sprint merger to go through this year, hence limiting the impact of carrier outdoor deployments, we expect new entrants like cable operators (perhaps in concert with DISH) to expand their mobile network capabilities first utilizing the CBRS band. Based on these somewhat speculative assumptions, our forecast shows an increasing share of North American market activities.

At the same time, our current forecast shows a diminishing volume shipments of carrier outdoor units in China. Based on our conversations with key vendors and operators in the region, it looks like volume shipments of outdoor small cells will diminish over time as the operators there focus on massive MIMO in the C-band to provide 5G mobile coverage that is equivalent to their LTE macro coverages in the lower 2GHz bands. While we generally agree with this view, we are also cognizant that provincial operators will continue to seek lower-cost Hi-Power Carrier Outdoor units to expand network capacity and coverage in rural parts of the country. Hence, we don't believe the decline will be very significant over the longer term. There is a possibility that Carrier Outdoor units, in integrated or RRH form, may rise if the 5G massive MIMO deployments in the C-band shows coverage "holes", especially in urban markets.

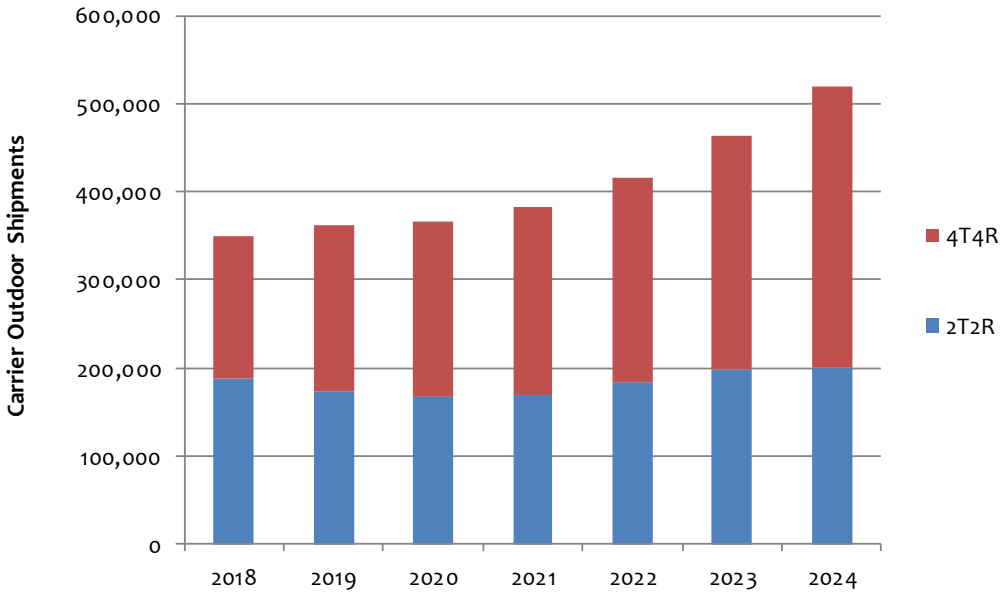


Source: Mobile Experts

Chart 40: Carrier Outdoor Small Cell Shipment Forecast, by Region, 2018-2024

Carrier Outdoor units are highly capable small cells with macro-like features such as high transmission power, higher user capacity, multimode/multiband support, etc. Many outdoor RRH units today support 4T4R. Also, we expect some Hi-Power Carrier Outdoor

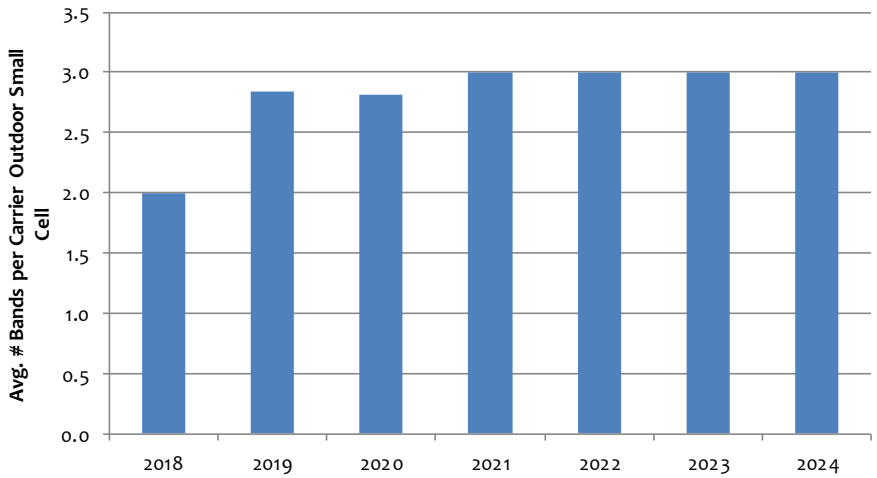
units to support 4T4R to take advantage of 4x4 MIMO devices coming to market. Thus, 4T4R configuration will be the dominant antenna configuration for the Carrier Outdoor small cells, even the initial low-power 5G RRHs.



Source: Mobile Experts

Chart 41: Carrier Outdoor Small Cell Forecast, by Antenna Configuration, 2018-2024

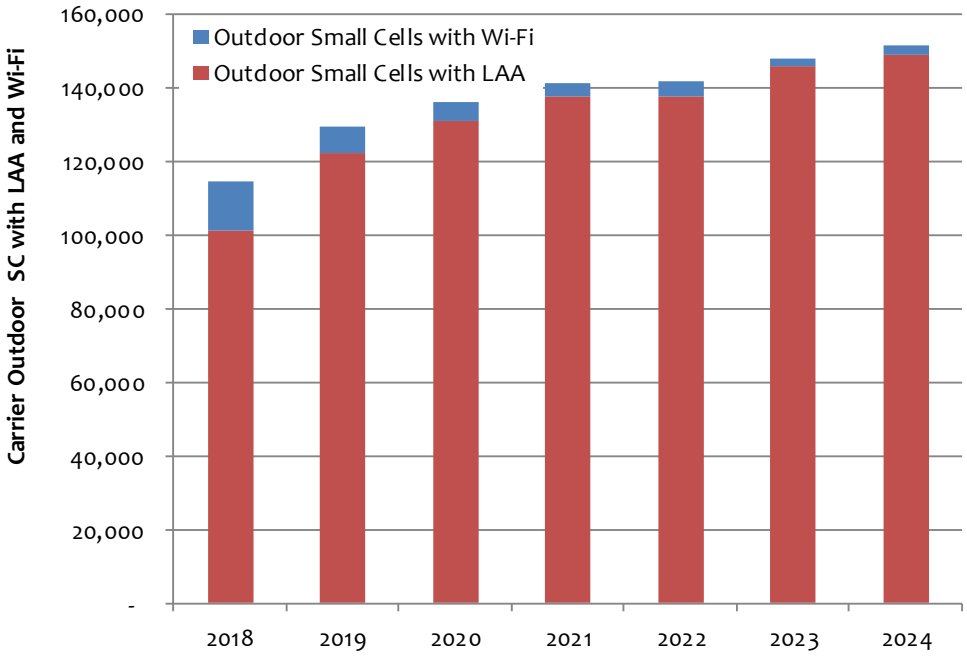
With many outdoor units supporting dual-band carriers, Mobile Experts predicts the average number of bands per Carrier Outdoor unit to increase over time from 2 to 3 during our forecast period. With some units supporting multiple RF modules that can be customized for licensed LTE (FDD or TDD), unlicensed Wi-Fi, and LAA, operators can aggregate multiple carriers to increase peak data rates and throughput capacity.



Source: Mobile Experts

Chart 42: Avg. # of Bands per Carrier Outdoor Small Cell Unit, 2018-2024

With more seamless network service integration with LAA over the 5 GHz unlicensed spectrum band, Mobile Experts predicts a high attach rate of LAA for carrier outdoor units versus indoor ones as operators have better control of where and how the 5 GHz unlicensed spectrum will be leveraged with LAA in outdoor contexts. Since most of Wi-Fi usage indoors is confined to inside of homes and commercial buildings, the noise floor of the 5 GHz band in dense urban areas is expected to be relatively low. Because of this, we expect the mobile operators to leverage LAA more extensively in outdoor applications since they can operate LAA in a "cleaner" RF environment with relatively high power small cells (higher than 50-100mW consumer-grade Wi-Fi units inside buildings). However, we believe the LAA use will plateau, instead of sharp increase as projected in last year's report. The main reason for this revision is our view that LAA will be more sparsely utilized in markets where operators have no more sub-6GHz spectrum to deploy. Based on the abundant spectrum resources that are coming available including the 150 MHz of CBRS band, the 3.7-4.2 GHz C-band, and over 1 GHz of the millimeter wave bands in the next couple of years will diminish the urgent desire for the North American operators to utilize the unlicensed spectrum that they can't fully control.



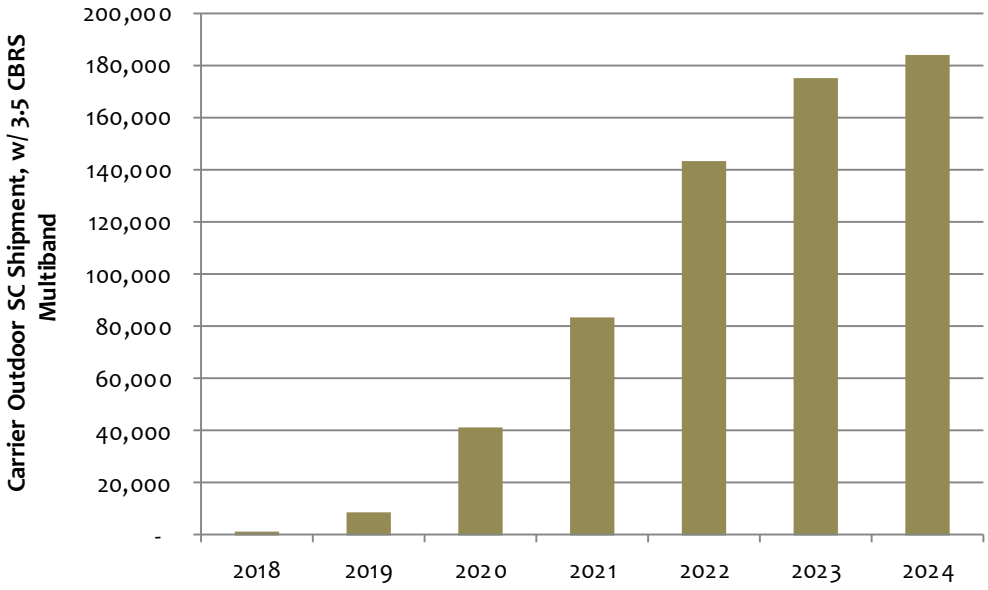
Source: Mobile Experts

Chart 43: Carrier Outdoor Small Cell Forecast, with LAA and Wi-Fi, 2018-2024

As LAA adoption increases, the need for Wi-Fi integrated small cells will decline. For applications where operators are required to install W-Fi (e.g., to fulfill municipality agreement to provide WI-Fi coverage in parks in exchange for siting), they may simply opt for standalone Wi-Fi access points. While LAA remains attractive in providing high peak

speeds, its attractiveness is largely confined to spectrum-constrained markets like North America and parts of MEA. For example, with a rich trove of licensed spectrum, there is no demand for LAA in China.

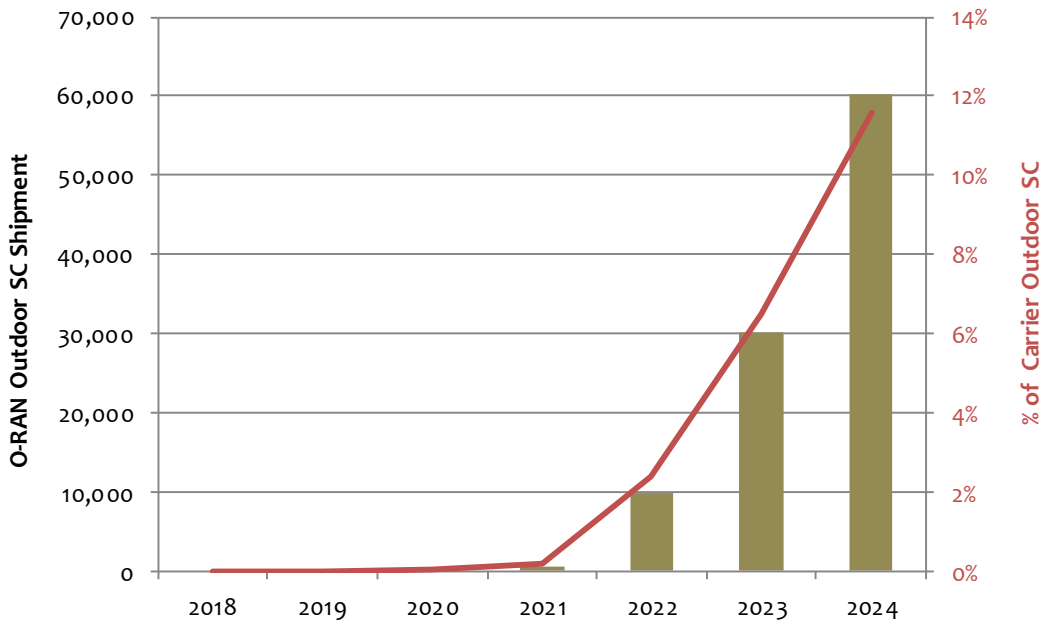
The operator demand for the CBRS band remains robust in the USA. We expect the attach rate of 3.5 GHz CBRS multiband on Carrier Outdoor small cells to reach over 180K units by 2024. While the CBRS ramp has been delayed about a year from our initial view, we believe the underlying demand by the operators has not diminished. Meanwhile, we have seen a growing number of CBRS-enabled smartphones which indicates to us that major operator support is there and eventual network investment will happen. While the initial small cell shipments will be small, we expect that to ramp up as the PAL auction takes place sometime in the last quarter of 2020 by our estimate. There is a chance that the timing of unit shipments may get delayed if the PAL auction timeline extends further out.



Source: Mobile Experts

Chart 44: Carrier Outdoor Small Cell Forecast, with 3.5 GHz CBRS Multiband, 2018-2024

While we believe Tier 1 operators will be more open to allowing O-RAN indoor small cells in their networks, we believe they will be more cautious about the Carrier Outdoor units which by definition must interact seamlessly with proprietary tier 1 vendor equipment across Core, baseband and split RAN components including CU-DU-RU. While the volume of O-RAN outdoor small cells is much less than the indoor units, we expect O-RAN small cells to make up only 10% of Carrier Outdoor small cells. We are aware that some tier 1 operators will be conducting some field trials thus year. We don't expect to see much volume in the near term. We estimate that the volume will start to pick up in 2022.

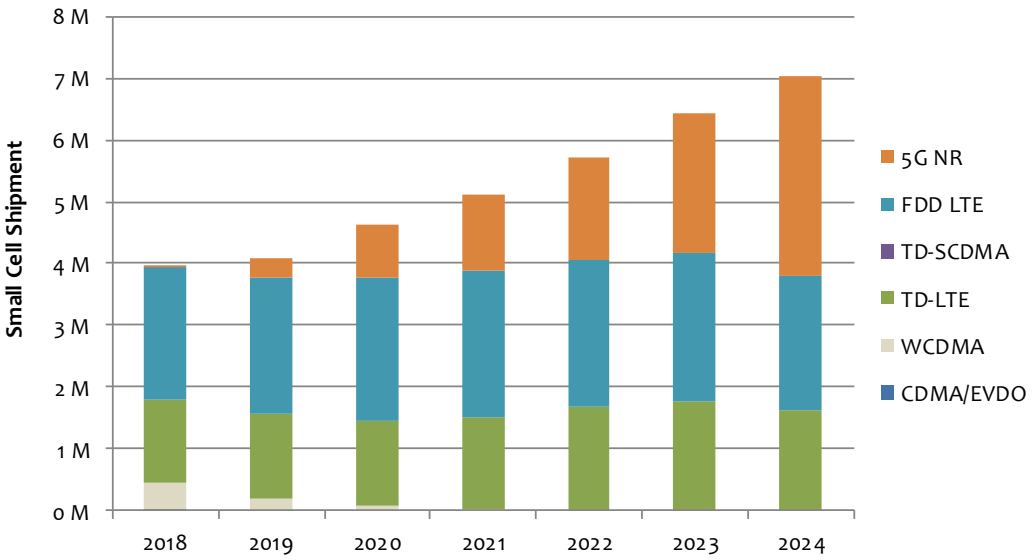


Source: Mobile Experts

Chart 45: Carrier Outdoor O-RAN Small Cell Shipment, 2018-2024

Small Cells by Air Interface

The shift to 5G is expected to happen much quicker than we had projected last year. From what we are hearing, the Chinese operators appear ready to ramp up 5G across both their macro networks as well as indoor venues via DRS radio units. While some of our sources are indicating much faster ramp than what we show below, we believe 2019 will be a transition year and don't expect DRS shipments and 5G deployments to be significantly higher than last year. We now predict 5G small cells in the form of DRS radio units to ramp up earnestly in 2020 as 5G DRS units replace installed base of LTE units and multimode 5G/LTE units in some facilities.

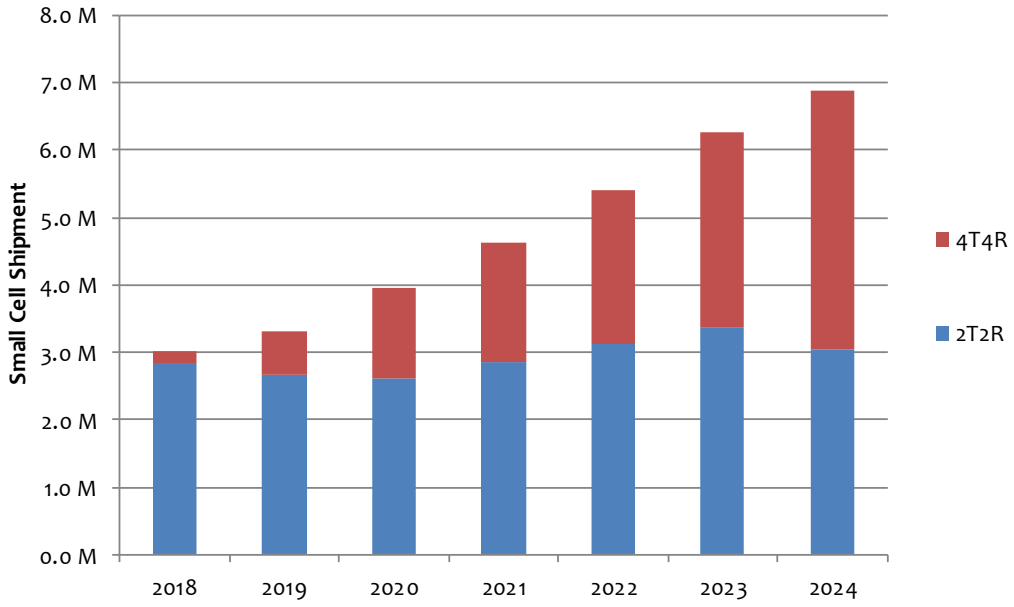


Source: Mobile Experts

Chart 46: Small Cell Shipments, by Technology, 2018-2024

Small Cells Antenna Configuration

As the small cell market shifts away from residential femtocells to carrier-grade units encompassing high-performance LTE features like carrier aggregation and multiband carrier support, small cell units will increasingly adopt higher order antenna configurations from 2T2R to 4T4R. Our forecast of a 4T4R share across the different small cell categories has been dramatically increased from last year. This revision reflects the rapid adoption of 5G indoor small cells, namely 5G DRS units that support 4T4R in the C-band in China. In addition to the 5G DRS units, LTE outdoor RRHs are mostly 4T4R nowadays to increase network capacity. In total, the 4T4R antenna configuration will become the dominant antenna configuration as 5G and LTE become prevalent on carrier-grade small cells.

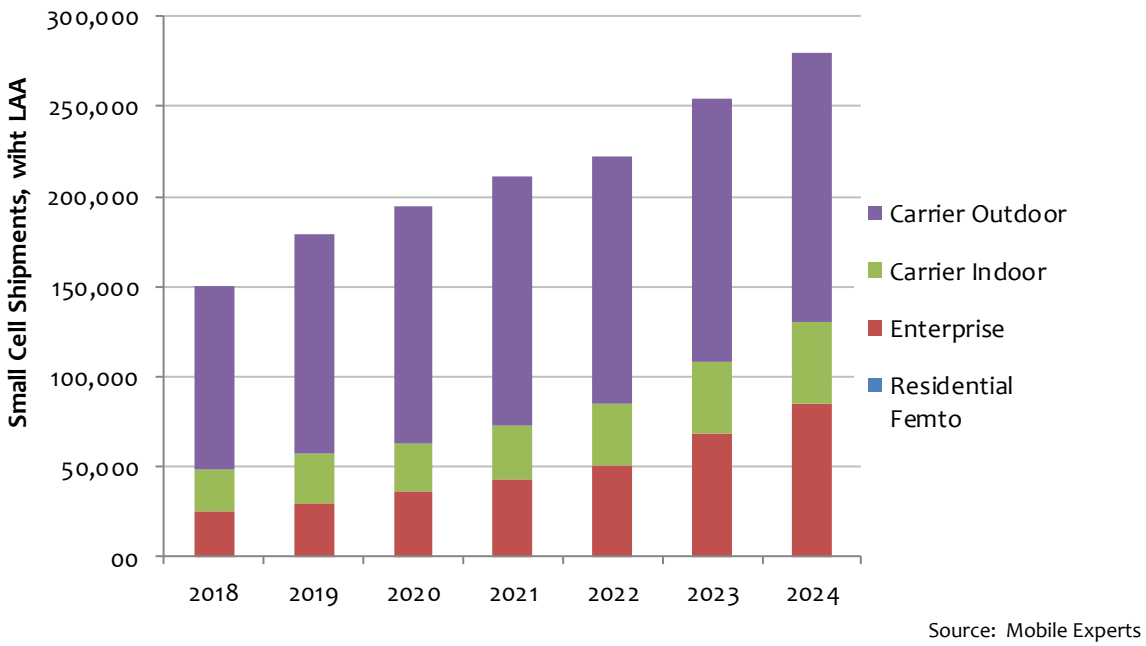


Source: Mobile Experts

Chart 47: Small Cell Shipment Share, by Antenna Configuration, 2018-2024

LAA Small Cells Forecast

Carrier aggregation of licensed and unlicensed bands through LAA is expected to provide an additional capacity boost for mobile operators seeking to claim "Gigabit LTE" services. For spectrum-constrained operators, especially the top mobile operators in the USA, LAA offers a seamless way to an aggregate unlicensed spectrum with a licensed carrier to boost user speeds and increase network capacity. We have been forecasting down the volume of LAA multiband small cells through our quarterly forecast updates in the past year to account for the limited appeal of this feature in other regions. For example, there is no demand for LAA in China where the operators have abundant licensed spectrum. We believe LAA is primarily appealing to certain operators in North America and parts of Southeast Asia, and MEA whose licensed spectrum per subscriber is limited. The ramp has been slower than anticipated, and we now believe that its appeal will wane as regulators open up hundreds of MHz of C-bands in preparation for 5G. We have revised our forecast of LAA small cells downward, and expect the volume shipment to reach under 300K units in 2024.

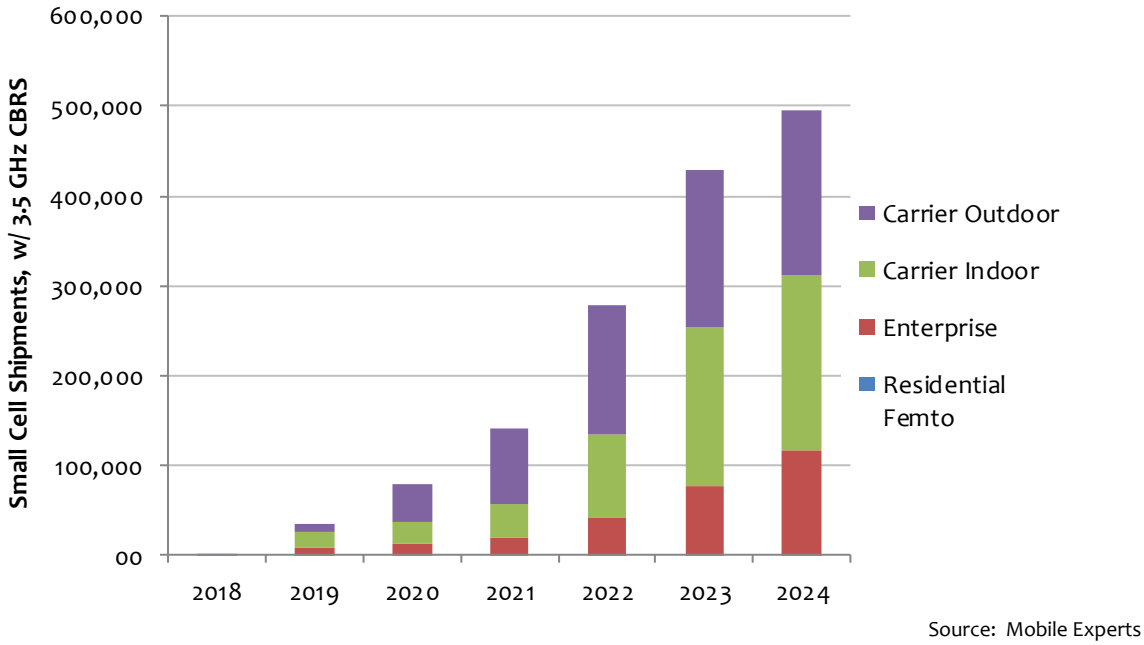


Source: Mobile Experts

Chart 48: Small Cell Shipment, with LTE-U/LAA, 2018-2024

CBRS Small Cells Forecast

The CBRS ecosystem in the USA is finally getting ready for commercialization after years of SAS and ESC development and testing that enable spectrum sharing to work. While our earlier forecast missed the mark on timing, we expect the volume of CBRS small cells will remain largely intact. We have removed the possibility of CBRS-enabled Residential Femtocells in our current forecast based on our discussions with the ecosystem vendors and operators. We expect the CBRS small cells to be adopted in Enterprise and Carrier units first before they find traction in residential devices.

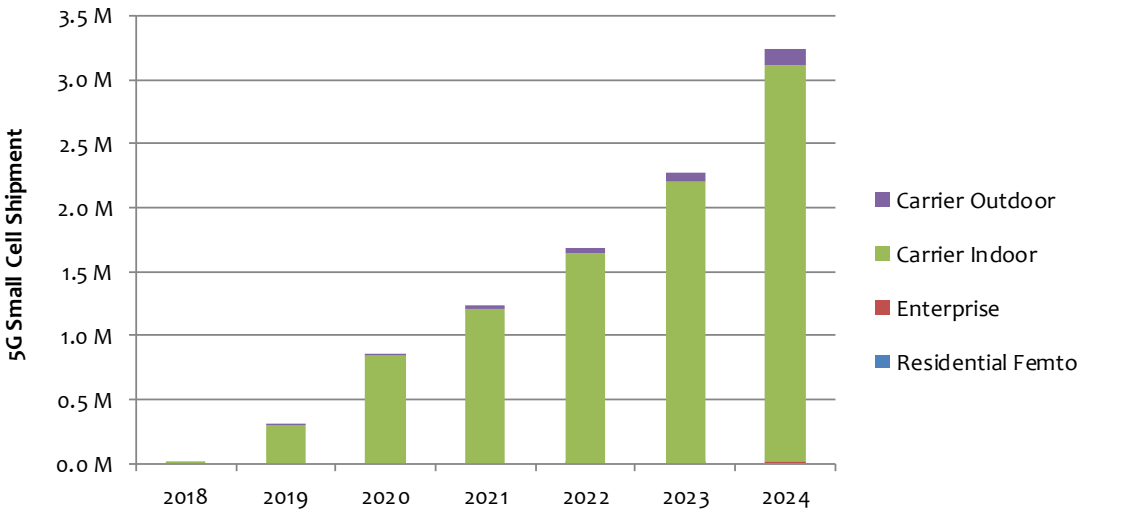


Source: Mobile Experts

Chart 49: Small Cell Shipment, with 3.5 GHz CBRS Radio, 2018-2024

5G Small Cell Forecast

While the 5G adoption is just now underway in North America, China, and APAC, our view of 5G adoption in Carrier Indoor small cells has shifted dramatically since last year. While we had initially expected the 5G rollout to occur at the macro layer and then gradually migrate into indoor small cells, what we are hearing is that 5G rollout in China will be simultaneous. In addition to massive MIMO adoption at macro layers, the Chinese operators appear positioning 5G DRS to enable 5G connectivity inside many key buildings. The faster pace of 5G adoption indoors implies that a significant portion of Carrier Indoor small cells dominated by the shipments in China will be 5G. Since 5G deployment outdoors will be driven by massive MIMO on macro base stations, 5G adoption on Carrier Outdoor small cells will be minimal. Mobile Experts forecasts the 5G small cells to quickly rise from hundreds of thousands this year to over 3M units in 2024 – most of these going to China and some in North America as some outdoor small cells are expected to support 5G on CBRS outdoor units.

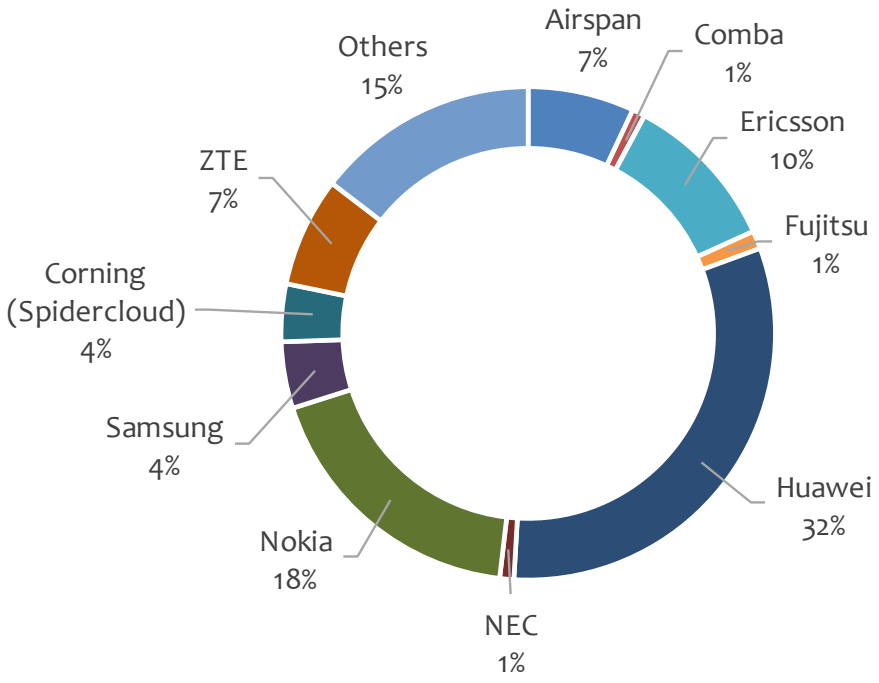


Source: Mobile Experts

Chart 50: 5G Small Cell Shipment, 2018-2024

7 MARKET SHARES

The small cell market grew 20% year over year to over $2.9B in 2018. Sizable growth in the Carrier Indoor segment in China aided Huawei to extend its overall revenue share lead in 2018. Meanwhile, Nokia held its own with moderate growth in higher value Carrier Outdoor small cells. Overall, the market expanded, and the tier 1 vendors including Huawei, Nokia, and Ericsson took reclaimed their revenue market share in the Small Cells market – reflecting their dominance in the Macro RAN market. In some respects, the Small Cells is becoming more reflective of the overall RAN market. The leaders in the Macro RAN market is also becoming the leaders in the Small Cells marketplace as small cells become an increasing share of operator RAN capital expenditures.



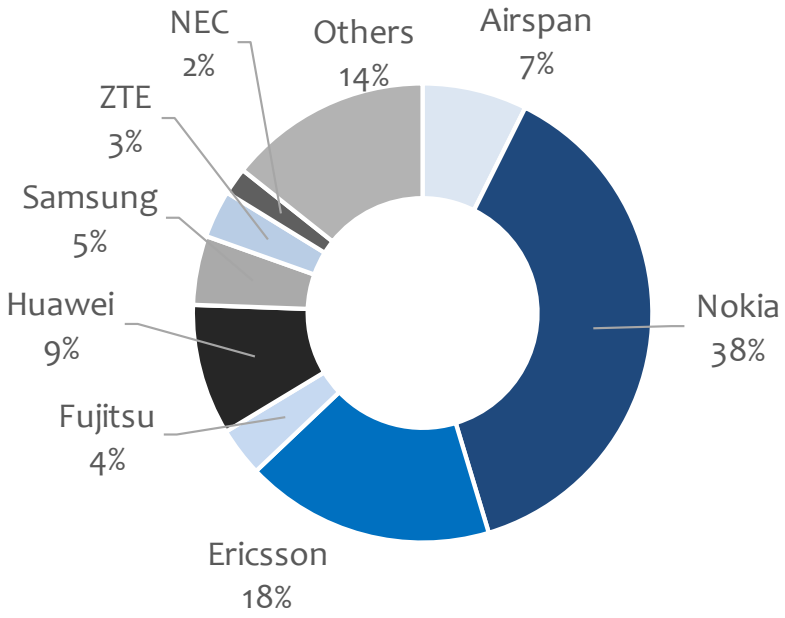
Source: Mobile Experts

Chart 51: Revenue Market Share by Revenue for Small Cells, 2018

Market Shares for Carrier Outdoor Small Cells

Every major infrastructure OEM vendor has an outdoor small cell offering. In general, these Tier 1 OEMs have leveraged their market advantage in extending their macro footprint via "macro parity" small cells in 2018. The top three Tier 1 OEM vendors have retaken their lead in Carrier Outdoor segment with LTE remote radio heads, and a full portfolio of different fronthaul/backhaul options including all-in-one integrated units, RRHs, and stand-mount types. Nokia continues to lead this particular segment with its long history of offering Hi-Power Mini Macros in North America and Japan. Ericsson has gained market share through its footprint in North America as operators have been

actively densifying their networks. Moreover, Airspan has leveraged its success in Wireless Relay to introduce strand-mount outdoor units last year. While Huawei has a full portfolio of outdoor and indoor small cell products, its share in the Carrier Outdoor segment is relatively low as outdoor small cell deployment in China is tame compared to other regions.

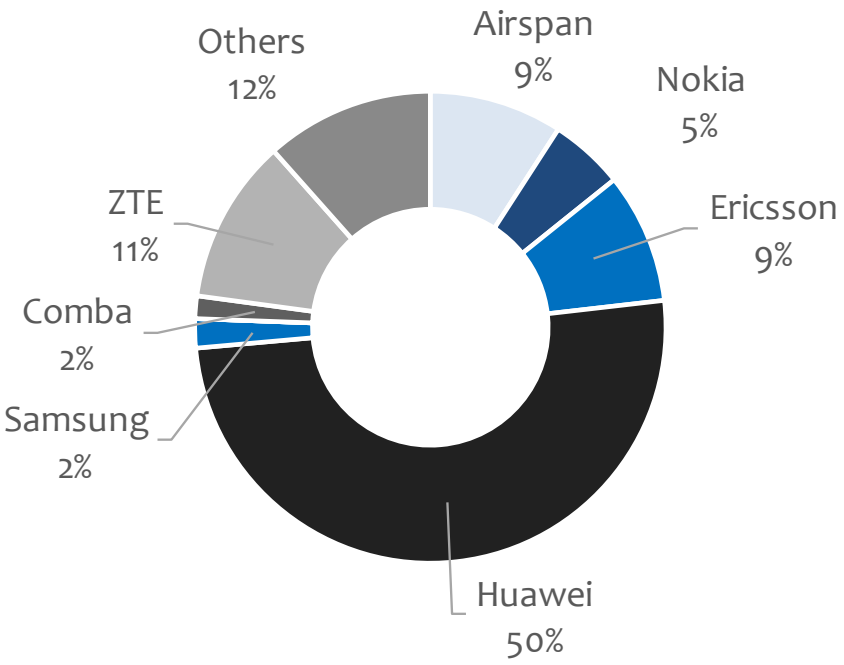


Source: Mobile Experts

Chart 52: Revenue Market Share for Carrier Outdoor Small Cells, 2018

Market Shares for Carrier Indoor Small Cells

Huawei has extended its lead in the Carrier Indoor segment as DRS shipments in China has doubled in 2018. ZTE also benefited from the rise of DRS shipments in China. While Nokia has also introduced similar DRS product called AirScale Indoor Radio (ASiR) in 2018, its volume shipment probably won't be as significant in China as the domestic vendors, Huawei and ZTE, will likely take the lion's share. While Airspan continues to ship its UE Relay product (i.e., "Magic Box" – the product name assigned by Sprint), its share has declined because the overall market has increased significantly year over year.

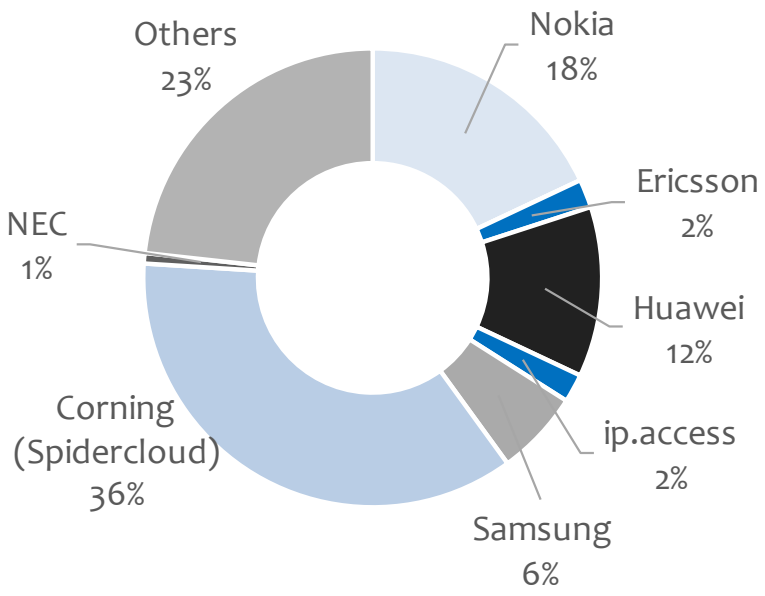


Source: Mobile Experts

Chart 53: Revenue Market Share for Carrier Indoor, 2018

Market Shares for Enterprise Small Cells

The Enterprise Small Cell segment is differentiated from the Carrier Indoor segment as enterprises have different priorities and requirements. However, carriers demand the same rigor in their approval processes as they don't want any Enterprise small cells to affect their macro network performance. Success in this market segment requires OEM vendors to satisfy both the operators and enterprise requirements. It is a challenging segment to succeed in, but some notable players have found market traction with tier 1 operators and certain enterprise channels. The major OEMs will also have a share of this market, but only for certain vertical segments where "macro parity" is essential to not disturb "public" operator networks. With Tier 1 vendors largely focused on Carrier Indoor and Outdoor segments, not much has changed since 2017 except that prior Enterprise small cells that sold through Cisco channel has now been assigned to Corning/Spidercloud.

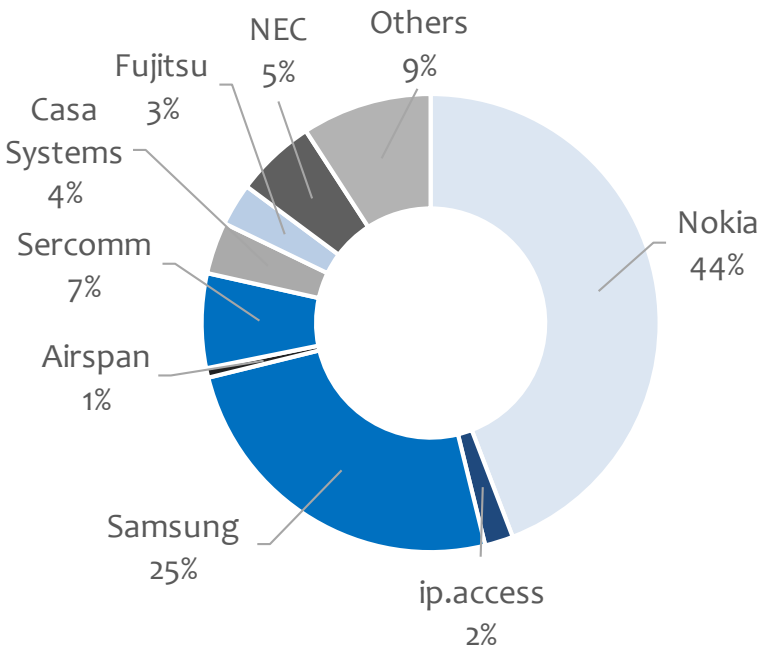


Source: Mobile Experts

Chart 54: Revenue Market Share for Enterprise Small Cells, 2018

Market Shares for Residential Femtocells

The residential femtocell market is a low-margin, high-volume business. We have seen several companies come in and out of the market over several years now. It is hard for any OEM vendor to solely focus on this segment for a sustainable business as margins are slim. Many of the leaders in this segment have other business lines to help subsidize their efforts here. Some established players like Samsung and Nokia view this segment as an opportunity to pursue other high-margin segments such as carrier-grade small cells, and ultimately Macro radios which are the ultimate prize for aspiring RAN vendors. Nokia and Samsung have long-standing carrier relationships with Tier 1 operators in North America to provide 3G/LTE femtocells. A major change in the past year is Casa Systems who have brought Core gateway and small cell products to market. It has shipped a meaningful quantity of units to several tier 1 operators in China and North America, and we expect the company to use this as a foundation to launch carrier-grade small cells in the years to come. With additional information, we have highlighted Japanese vendors who serve the domestic market in this year's report.



Source: Mobile Experts

Chart 55: Revenue Market Share for Residential Femtocells, 2018

8 COMPANY PROFILES

ACCELLERAN:

Accelleran is a small cell OEM start-up based in Belgium focusing efforts to produce LTE TDD small cells, targeting both licensed and shared 3.5GHz CBRS band for the US. At the MWC 2017, the company released its CBRS small cell based on Cavium SoC (now Marvell). The company has a few CBRS trials ongoing and is in the process of getting its radio certified. www.accelleran.com

AIRHOP:

AirHop Communications is a San Diego based company providing SON solutions for dynamic resource optimization and network management of heterogeneous networks. Founded in 2007, the company's eSON and eSON360 solutions have been incorporated in several small cell deployments. Most recently, the company has been selected by SK Telecom to collaborate on 5G SON software implementation as part of TIP initiative. www.airhopcomm.com

AIRSPAN:

Airspan Networks has developed a line of LTE small cells, including indoor enterprise units and outdoor units with integrated wireless backhaul. The company introduced LTE Relay system to boost network efficiency at the cell edge. The company has hundreds of thousands of small cells at Sprint and tens of thousands of units in India, Japan, and other regions. The company acquired Mimosa who has a line of wireless backhaul and fixed wireless access products that operate in unlicensed bands. The company continues to expand its product portfolio ranging from indoor and outdoor radios that span sub-6GHz, millimeter wave, and several unlicensed bands for relay and backhaul. www.airspan.com.

ALTIOSTAR:

Altiostar has developed a split-baseband LTE RAN product line, which they are targeting at macro and small cell deployments. The company has set up a proprietary baseband partition in which the scheduler sits in the radio head, allowing higher latency in the transport and much lower bandwidth for lower transport cost. The company has announced its virtualized RAN solution and is conducting lab trials with few tier-one operators, including SK Telecom. The company has been chosen as the virtualized RAN provider by Rakuten in Japan whereby its vRAN worked in concert with Nokia RRH. With a fresh round of funding including strategic funding from Rakuten,

the company is expanding its operation to support the key customer in Japan and other O-RAN opportunities. www.altiostar.com

ARGELA:

Argela has close connections with Turkish mobile operators. As a part of Turk Telekom Group, Argela has a more direct route to market than other femtocell suppliers. The company recently demonstrated its ProgRAN solution that encompasses the programmable RAN solution based on the NFV/SDN principles. The platform was based on Cavium's baseband processor. www.argela.com

ARRIS (RUCKUS):

With the Ruckus Wireless acquisition, ARRIS has significantly boosted its LTE small cell and Wi-Fi product portfolio. Ruckus Wireless has historically leveraged its adaptive antenna technology to deploy high-capacity, interference resistant Wi-Fi access points, and has focused on Wi-Fi offload for carriers. The company has been one of the leading proponents of CBRS/OnGo, which started with its OpenG technology initiative to provide cellular coverage and capacity indoors by leveraging the CBRS band for neutral host capable small cells. As a result of a series of complicated deals with Brocade, Broadcom, and ARRIS, the resulting Ruckus subsidiary has inherited the history Wi-Fi and CBRS/OnGo product portfolio as well as wired enterprise networking gears. Ruckus has now become an enterprise networking subsidiary of ARRIS. The company has announced its plan to merge with Commscope. www.ruckuswireless.com

BAICELLS:

Founded in 2014, Baicells is a privately-held company based in Beijing, China. The company's product solutions range from indoor and outdoor small cells, CPEs, and antennas. With a new sales office in the US, the company is expanding into unlicensed and shared spectrum opportunities with cable operators, neutral host providers, and WISPs. The company is also very active in O-RAN trials with China Mobile on indoor small cell product and with Telefonica on outdoor small cell. www.baicells.com

BENETEL:

Based in Dublin, Ireland, Benetel is a system design house focusing on small cell design and development. The company has a portfolio of baseband and RF modules and works with leading OEMs for custom design and development projects. The company's new design center opening in Poland may portend small cell market growth

and market requirements for low-cost development and fast time-to-market production. www.benetel.com

BLINQ NETWORKS:

BLiNQ Networks is a Canadian company that has a long history of developing RAN equipment across multiple technologies. Now, as a part of Communications Components Inc (CCI), BLiNQ has introduced FCC-certified outdoor small cell with integrated antenna system. The company has announced its plan to introduce other CBRS small cell solutions that support Massive MIMO and a strand-mount option. www.blinqnetworks.com

BRAVOCOM:

BravoCom is China-based communication technology vendor with early history of developing small cell products for the Chinese domestic market. It has similar small cell products like those of Huawei's Lampsite and Ericsson Dot. www.bravocomtech.com

CASA SYSTEMS:

Headquartered in Andover, MA, Casa Systems was founded in 2003 with core business in cable broadband and video product solutions The company has since expanded its product solution portfolio to include wireless products addressing carrier Wi-Fi and small cell products. The company recently announced customer wins at China Mobile, Telefonica Spain, and Sprint for its small cell and small cell core gateway products. With its core business in the cable industry, the company has been expanding into wireless with several outdoor and indoor small cell product launches at MWC 2019. With several mobile customer wins in the femtocell category, the company is rapidly introducing carrier-class outdoor small cell products that can support both sub-6GHz and millimeter wave bands. www.casa-systems.com

CISCO:

While Cisco's "direct-to-enterprise" small cell strategy has ended last year with Corning's acquisition of Spidercloud, Cisco is the leading enterprise wireless networking supplier. With its extensive channel partnerships, the company has partnerships to furnish CBRS/OnGo radio and the end-to-end LTE small cell solution. While the company's radio strategy is still largely planted in Wi-Fi and IEEE 802.11 roadmap, it is a major LTE and 5G Core supplier in several key service provider markets including N. America, Asia, and Europe, and in private LTE markets. www.cisco.com

COMBA TELECOM:

Comba holds a strong position in supporting coverage solutions in China, as well as a few South Asian and Latin American markets. The company supplies a wide range of repeaters, DAS, residential and indoor small cells, and other coverage related products. Comba has been highlighted as the first supplier of a "nanocell" for TD-LTE trials for China Mobile. www.comba-telecom.com

COMMSCOPE:

Commscope is a global leader in fiber connectivity and DAS systems whose IPR and product portfolios in in-building wireless space were expanded with acquisitions of TE Connectivity and Airvana. With the Airvana acquisition in 2015, Commscope has formally introduced a small cell product based on Airvana's OneCell. The OneCell concept combines aspects of small cells, DAS, and Cloud RAN to create a flexible in-building solution that can dynamically allocate capacity throughout a building, while avoiding some of the high-cost items associated with DAS, and providing CRAN features such as CoMP and eICIC. The company has announced its plan to acquire ARRIS in 2018. With combined assets across a diverse customer base that includes cable and mobile operators and product portfolio ranging from fiber, cable infrastructure, set-top boxes, enterprise networking, and small cells, the company continues to expand its wired and wireless solution portfolios.
www.commscope.com

CONTELA:

Contela had provided femtocells and related gateways for the Japanese and Korean markets, and has ramped to significant volume with more than 80,000 LTE small cells for SK Telecom in the past. In 2018, the company has been selected to co-develop a 5G Small Cell with SK Telecom and ETRI that can support both the 3.5 GHz C-band and the 28 GHz band. www.contela.com.kr

CORNING (SPIDERCLOUD WIRELESS):

SpiderCloud has been in commercial service since December 2011 and has major customer wins with America Movil, AT&T, Sprint, Verizon, and Vodafone. The company is seen as a major player in the enterprise segment with expanding product features and spectrum bands, including LTE-U/LAA, CBRS, MulteFire, Private LTE, etc. The company is focused on enterprise networks, using a centralized controller to coordinate clouds of licensed/unlicensed/shared LTE radio nodes attached via Ethernet LAN/WAN transport. The company has established a key partnership with Cisco, where they work together to outfit both indoor and outdoor Cisco Wi-Fi APs in the field with

"plug-in" modules. The company was acquired in 2017 by Corning to enable the provisioning of total cellular solutions to enterprises. www.spidercloud.com

CROWN CASTLE:

A traditional wireless tower company that is taking a more active role in the small cells infrastructure business. The company has made several fiber acquisitions in the US to bolster its small cells business by offering both backhaul transport (primarily dark fiber) and site leases for mobile operator customers to deploy small cells or outdoor DAS remote radio heads in key markets. The company's wireless infrastructure consists of 40,000 towers and 17,000 route miles of fiber. www.crowncastle.com

DATANG:

Based in Beijing, Datang Mobile has been involved in IMT 2020 "Digital Indoor System" (DIS) tests in China. It has achieved favorable test results from the IMT 5G DRS test trials and expect to receive 5G DIS contracts in China in the future years as Chinese operators ramp up 5G indoor network coverage in coordination with their 5G massive MIMO C-band macro deployments. However, their portion will be relatively small in the context that they are competing against all major vendors in the market including Huawei, ZTE, Nokia, and Ericsson. www.datangmobile.cn

ERICSSON AB:

At Ericsson, radio technology has always been its core strength, and the company comes into the 5G market with deep capability in the integration of the radio, antenna, and baseband processing. Ericsson also recently agreed to acquire Kathrein-Werke, which adds significant antenna depth to the team. Ericsson has also invested heavily in virtualized core networks and Cloud infrastructure to support mobile applications. Besides its core strength in Macro radios, the company introduced StreetMacro class of radio products operating across both Sub-6GHz and the millimeter wave band to expand its market opportunity with Verizon and AT&T in North America. Its Radio Dot is a key small cell platform to address the demand in China and other indoor applications where extending mobile coverage deep inside a building is a key driver. www.ericsson.com

EXTENET SYSTEMS:

Extenet Systems is a privately-held wireless infrastructure provider of distributed networks. As a part of Digital Bridge holdings, the company designs, owns, and operates neutral-host networks leveraging multiple technologies including small cells,

Wi-Fi, RRH, DAS, and other technologies on behalf of mobile operators and enterprise customers. The company partners with major operators to build out operators' small cell deployments including Verizon small cell deployment in San Francisco. The company has been linked to several CBRS-related deployments in the past year. www.extenetsystems.com

FEDERATED WIRELESS:

Federated Wireless is one of the leading SAS providers in the CBRS ecosystem. Along with Google and Commscope (Comsearch), the company provides the critical SAS service which is necessary to operate in the CBRS band. The company has been expanding the CBRS market opportunities across many sectors including those in Fixed Wireless Access and most recently in MEC. The company established the Kinetic Edge Alliance along with Packet, Vapor IO, MobiledgeX to enable private networks using CBRS. www.federatedwireless.com

FUJITSU:

Fujitsu is one of the leading telecom infrastructure suppliers in Japan. The company supplies residential femtocell and outdoor small cell units to domestic carriers. The company recently partnered with Ericsson to supply 5G network solutions for the domestic market. www.fujitsu.com

GOOGLE (ALPHABET):

With its core business of Internet search/advertising today, it may seem odd to put Google on our list of small cell company profiles. With its many wireless and telecom related activities, however, we have decided to put a placeholder here to signify the possibility of Google's influence in the small cells marketplace especially in light of its significant policy and ecosystem development efforts in the 3.5GHz CBRS space as well as other wireless/telecom initiatives already in progress, including Google Fiber, Google Fi, millimeter wave experimental trials, and not to mention its heavy influence in the device ecosystem with Android. The company made a wave at a recent WISP event in North America where it announced a pretty low rate for SAS service. The company has partnered with Commscope to co-invest/develop ESC network. www.google.com

HUAWEI TECHNOLOGIES:

Huawei is a shipment leader in non-residential small cells with huge success with its LampSite product line in China. The first two generations of LampSite, which can best be described as a low power RRH product with distributed RF, has been hugely popular

in China and Southeast Asia. The product provides flexible indoor coverage/capacity solution with 'macro parity' features so that operators can reduce operational and management costs associated with running multi-layer networks. The company has focused its efforts on multi-band small cells for higher capacity carrier applications. With the next-generation LampSite, Huawei is targeting other regions including Europe where RAN sharing is more common. While it has other small cell products targeting outdoor, it does not believe there is a huge market for outdoor small cell products. www.huawei.com

INNOWIRELESS (QUCELL):

Based in Korea, Innowireless provides network testing and optimization solutions. Most of its revenue is derived from testing/optimization services in North America. The company delivered tens of thousands of small cells to Korea Telecom for their LTE capacity upgrades during 2012 and 2013, acting as an ODM with a Cavium chipset and using software developed by third parties and by KT themselves. Recently, the company, under the "Qucell" brand, has been introducing both FD-LTE and TD-LTE residential, indoor, and outdoor small cells based on Qualcomm chipset to KT, Fujitsu and others. www.qucell.com

INTEL:

Intel's small cell journey started with its acquisition of Mindspeed back in 2014. These days, Intel exposure to the mobile infrastructure market is related to baseband processing Virtualized RAN implementations using the X86 architecture. Intel's strong presence in the Cloud RAN area gives them a window into upcoming 5G deployments. At MWC 2019, Intel demonstrated a 5G repeater product to illustrate a battery-powered repeater concept. Intended for busy-hour use or possibly in venues that have a short surge of traffic, the mm-wave repeater could extend the range of 5G RAN infrastructure with in-band backhaul. www.intel.com

IP.ACCESS:

Ip.access has been focusing on several vertical markets including enterprise private networks, security & surveillance, transportation, and rural markets. It continues to ship residential femtocell products to operators in Europe and India, but the company's main focus is around private LTE markets where unique market requirements may provide higher margin business opportunities. www.ipaccess.com

JMA WIRELESS:

JMA Wireless, based in Liverpool, NY, is one of the leading DAS suppliers with a strong lineup of in-building wireless solutions and other mobile infrastructure products including antenna solutions. The company has been expanding its in-building wireless solutions with the introduction of CellHub remote radio unit and XRAN virtualized baseband solution. In addition, the company acquired PHZR, a Texas-based start-up which has developed a millimeter wave small cell solution. www.jmawireless.com

JUNI:

With a research and development center in Korea, Juni has been developing LTE small cells based on Intel platform since 2009. It is focusing on the CBRS market and has a trial ongoing in this space. www.juniglobal.com

MARVELL (CAVIUM):

As an established chipset supplier in Layers 4-7 for 3G core networks, Cavium started in a difficult position but has emerged as a strong contender for Layers 1-7 by combining higher count of processor cores and higher clock speeds in some very high-performance SoCs. The key to the Cavium approach is to build in enough horsepower and memory that data flows through accelerators and processors without copying to memory, for an efficient solution. Cavium penetrated the early market in Korea with large volume shipments of carrier-grade small cell SoC. The company has gained design win with Samsung and is working closely with Samsung on 5G baseband. www.cavium.com

NEC:

NEC has successfully deployed significant numbers of indoor and outdoor small cells for Softbank and other operators in Japan but is not highly visible outside of Japan in radio hardware. NEC has partnerships with SpiderCloud to offer 3G/LTE and LTE-LAA solutions for the enterprise segment outside of Japan. More recently, the company won a 5G supply deal with NTT docomo where it will be supplying control units for 5G base stations. http://www.nec.com/en/global/solutions/nsp/sc/index.html

NOKIA:

Nokia is a strong RAN vendor with a strong end-to-end portfolio across wireline and wireless products. Nokia has been an early mover in small cells. With Alcatel-Lucent acquisition, the company acquired a suite of residential femtocell product line and has been streamlining the product portfolio there which are based on Qualcomm SoC. The company also has a strong product line of outdoor and indoor small cells based on its own chipset solution. Last year, the company joined its competitors in introducing DRS solution called AirScale Indoor Radio (ASiR) to address the needs of Chinese operators who have standardized on this architecture. The company is introduced several 5G millimeter wave small cell products at MWC 2019. www.nokia.com

OCTASIC:

Octasic supplies DSP processors for small cells and has a surprisingly high number of design wins for a small company. Octasic avoids competing with the big 'gorillas' in the industry by focusing on specialty markets including law enforcement, public safety, mining and oil exploration, and rural markets. The company has announced an LTE and 5G SoC solution that can operate as either a small cell or a user device. The company claims that using the same component for base station and user equipment simplifies application development ideal for private wireless and IoT applications.
www.octasic.com

PARALLEL WIRELESS:

Since coming on the scene, Parallel Wireless has introduced several solution offerings targeted at different segments of the market. It has launched its distributed small cell architecture solution leveraging Intel SoC for small cells and HetNet Gateway to ease the deployment of LTE infrastructure. Its rural small cell deployment at EE, and HetNet Gateway solution for the enterprise market has been well received in the market. More recently, it launched so-called "Band 14 in a box" to target the Public Safety market, or more specifically FirstNet system in the US. The company has showcased many interesting use cases of both high-power and low-power small cells in rural/remote applications in the UK, Australia, and the US. www.parallelwireless.com

PHLUIDO:

This San Diego-based start-up is working to define and develop a virtualized radio stack based on split-baseband RRH architecture to alleviate high fronthaul requirements and

costs associated with managing virtualized RAN. The company's "radio-as-a-service" solution emphasizes the key value proposition of running virtualized radio access network via less costly fronthaul links. The company has been expanding its trials and exposure in "open" ecosystems such as TIP, O-RAN, and Terragraph. www.phluido.net

QUALCOMM:

Qualcomm is now the dominant chipset supplier to the small cell industry. Since its acquisition of DesignArt, Qualcomm has been continuously investing in this segment to expand beyond its stronghold in the handset market to mobile infrastructure. More recently, it has expanded its OEM partnerships with SpiderCloud, Samsung, and many others to expand into licensed, unlicensed and shared spectrum bands. By leveraging much of the research and development from the handset side, the company has been able to expeditiously and in close coordination, to introduce complementary small cell infrastructure SoC platforms, including a new generation of small cell SoC that supports LAA, CBRS, and 5G across both sub-6GHz and millimeter wave bands. www.qualcomm.com

SAMSUNG:

Samsung has deployed millions of CDMA femtocells in North America, with both Sprint and Verizon Wireless using the Samsung "UbiCell" for initial deployments. Samsung also supplied picocells for WiMAX networks, so they have easily converted to LTE small cell products, which have been selected by Sprint and a few other operators for ongoing LTE deployment. Most recently, Samsung has partnered with Qualcomm to support LTE-U/LAA capable femtocells. Samsung has been a key infrastructure supplier for Reliance Jio's LTE rollout and looks to expand its infrastructure business in North America with learnings from the Jio network buildout. Samsung has a portfolio of residential, enterprise, and carrier-grade small cells along with its macro product line used in the Jio rollout. www.samsung.com

SERCOMM:

Based in Taiwan, Sercomm supplies residential and enterprise small cells as well as Wi-Fi routers in several regions. The company has taken the obvious step of integrating their Wi-Fi router and femtocell products together. Recently the company has focused on China and TD-LTE applications, and supplies TD-LTE, FDD-LTE, and dual-mode TD-SCDMA/TD-LTE small cells to that market. The company has also developed CBRS-capable small cell for the North American market. www.sercomm.com

XILINX:

Xilinx supplies field-programmable logic chips to the telecom industry for applications in baseband and radio equipment. The Xilinx RFSoC handles a wide bandwidth and could become a leading contender to perform the data conversion and basic up/downconversion functions of the RU, along with an up/downconverter to set the RF frequency to 24 or 28 GHz as needed. www.xilinx.com

ZTE:

ZTE is a major RAN vendor and offers a complete line of small cell products, and should be considered a major contender in the domestic Chinese market. Along with Huawei, ZTE has supplied a meaningful share DRS radio units, especially to China Telecom. The ZTE product line is based on software-defined radios based on Texas Instruments SoCs which have the horsepower to run macro-level software for ideal coordination in a multimode HetNet. While the company introduced several 5G millimeter wave radio products at MWC 2019, we don't expect the Chinese operators to invest in this spectrum band; thus they probably won't be involved in this class of small cells for the next several years. www.zte.com.cn

9 ACRONYMS

2G: Second Generation Cellular

3G: Third Generation Cellular

3GPP: Third Generation Partnership Project

4G: Fourth Generation Cellular

5G NR: 5G New Radio, global 5G air interface standard

5GTF: 5G Technology Forum, a Verizon-led industry forum for 28/39GHz fixed wireless access trial and deployment)

ADC: Analog-to-Digital Converter

ARPU: Average Revenue Per User

ASIC: Application Specific Integrated Circuit

BBU: Baseband Unit

BSC: Base Station Controller

BTS: Base Transceiver Station

Bits/Hz/sec: Digital bits transmitted per Hertz of bandwidth per second

CA: Carrier Aggregation

CAT-5: Category 5 Ethernet cable

CBRS: Citizens Broadband Radio Service, a shared wireless broadband use of the 3550-3700 MHz (3.5GHz) band in the US

CDMA: Code Domain Multiple Access, a 2G radio interface

CLEC: Competitive Local Exchange Carrier

CoMP: Coordinated MultiPoint

CPRI: Common Public Radio Interface, a non-profit organization and interface format

CU: Central Unit (in Open RAN context)

DAC: Digital-to-Analog Converter

DAS: Distributed Antenna System

dBm: Decibels of power relative to 1mW

DRS: Distributed Radio System

DSP: Digital Signal Processing or Digital Signal Processor

DU: Distributed Unit (in Open RAN context)

eICIC: Enhanced Inter-Cell Interference Coordination

eNB: e Node B, or the radio access node for LTE

EIRP: Effective Isotropic Radiated Power, an amount of power a radio transmitter and antenna radiates

ESC: Environmental Sensing Capability, applicable for 3.5 GHz CBRS, detects incumbent use of the 3.5 GHz shared spectrum

FDD: Frequency Division Duplexed

FPGA: Field Programmable Gate Array

GAA: General Authorized Access, applicable for the 3.5GHz CBRS, the lowest priority access, similar to unlicensed spectrum use

GB: Gigabyte

Gbps/km2: Gigabits per second per square kilometer

GGSN: Gateway GPRS Support Node

GHz: Gigahertz

GSM: Global System for Mobile communications, a 2G radio interface

GW: Gateway (normally referring to a femto gateway)

HetNet: Heterogeneous Network

HNB: Home Node B (femtocell)

HSPA: High Speed Packet Access

HSPA+: A subsequent evolution of HSPA with higher throughput

HVAC: Heating, Ventilation and Air Conditioning

Hz: Hertz (cycles per second)

IC: Integrated Circuit

IDAS: Indoor Distributed Antenna System

IMS: IP Multimedia Subsystem

IP: Intellectual Property

I/Q: In-phase/Quadrature modulation, a typical digital format for communications signal

I-ub: Interface standard for base stations

I-uh: Interface standard for femtocell to serving gateway

Km: Kilometer

Low-E: low-emissivity glass that inhibits heat transfer. As a consequence, cellular signal does not penetrate well outside in

LTE: Long Term Evolution, a "4G" radio interface based on orthogonal frequency division multiplexed data

LTE-A: LTE Advanced, a higher bandwidth version of LTE

LTE-LAA: LTE-License Assisted Access, a 3GPP-compliant LTE-U technology

LTE-U: LTE-Unlicensed, a technology to run LTE waveform on 5GHz unlicensed spectrum band

OBSAI: Open Base Station Architecture Initiative, a non-profit organization, and interface format

MAC: Media Access Control layer

MEA: Middle East and Africa

MHz: Megahertz

MIMO: Multiple Input, Multiple Output

MS: Mobile Station

mW: Milliwatt

NR-SS: NR Spectrum Sharing (Qualcomm term describing 5G NR in unlicensed bands)

OBSAI: Open Base Station Architecture Initiative

O-DAS: Outdoor Distributed Antenna System

OEM: Original Equipment Manufacturer

OFDM: Orthogonal Frequency Division Multiplexed

O-RAN: Open RAN (Alliance)

PAL: Priority Access License, applicable for the 3.5GHz CBRS

PB: Petabyte

PC: Personal Computer

PHY: Physical layer

QPSK: Quadrature Phase Shift Key

QAM: Quadrature Amplitude Modulation

QoS: Quality of Service

RAN: Radio Access Network

RF: Radio Frequency

RN: Relay Node

RNC: Radio Network Controller

RRH: Remote Radio Head

RU: Radio Unit (in Open RAN context)

SAS: Spectrum Access System, to coordinate spectrum sharing in 3.5GHz CBRS

SGSN: Serving GPRS Support Node

SIP: Session Initiation Protocol

SNR: Signal-to-Noise Ratio

SoC: System on a Chip

TB: Terabyte

TD-LTE: Time Domain-based Long Term Evolution

TD-SCDMA: Time Domain Synchronous Code Domain Multiple Access

UE: User Equipment

VoLTE: Voice over LTE

VoWiFi: Voice over Wi-Fi (sometimes referred to as "WiFi calling")

W: Watts

W-CDMA: Wideband Code Domain Multiple Access, a 3G radio interface

Wi-Fi: Wireless Fidelity (802.11 data communications)

WiMAX: Worldwide Interoperability for Microwave Access (a "4G" standard)

10 METHODOLOGY

To create estimates and forecasts for small cell shipments and revenues, Mobile Experts relied on direct input from more than 60 industry sources, with 30 mobile operators contributing to the overall analysis to give a detailed global view of the market. Mobile Experts built a "top-down" forecast based on direct input from mobile operators and based on trends in end-user demand for mobile services. Then, Mobile Experts built a "bottom-up" forecast through discussions with the supply chain. Roughly 40 suppliers, integrators, and OEMs participated in this phase of the survey. Mobile Experts also used financial disclosures from publicly traded companies to assemble a quantitative view of the equipment market.

This year, Mobile Experts has changed the model framework to track four categories: Residential / Enterprise / Carrier Indoor / Carrier Outdoor. The previous category of Hi-Power units are tracked under the Carrier Outdoor but is tracked separately as a sub-category. Portions of the Distributed Radio Systems such as Radio Dot and LampSite are tracked under the Carrier Indoor and Carrier Outdoor segments.

The independent market for Carrier Wi-Fi is not included in this analysis, but the integration of Wi-Fi into licensed-band small cells is considered. In this report, we cover the integration of unlicensed and licensed-band connectivity, and shed light on the prospects for specific LAA/Wi-Fi/CBRS integration options.

Figures 19 through 22 give the detailed definitions for each category of equipment, for regions of the world, for multimode vs. single mode, for frequency band categorization, and for small cells as a service categorization.

Definitions	RF Power	Backhaul	Architecture
Macrocell	40W+ composite	Operator managed	Closely controlled cells
Traditional Microcell	5.1-29W composite	Operator managed	RNC or BSC architecture (2G/3G)
Traditional Picocell	300 mW to 5W composite	Operator managed	RNC or BSC architecture (2G/3G)
Low power CPRI RRH	up to 1W per antenna	CPRI, OBSAI, ORI to separate baseband unit	No baseband processing in radio unit
Low Power Split-Baseband RRH	up to 1W per antenna	Proprietary format	Split baseband with scheduler in RRH and other baseband functions centralized
Carrier Outdoor (High Power) Small Cell	5.1W/ant-40W composite	Operator managed	Coordinated with macro layer, LTE or 3G gateway; some fixed wireless application
Carrier Outdoor (Low Power) Small Cell	300 mW to 5W per antenna	Operator managed	Coordinated with macro layer, LTE or 3G gateway
Carrier Indoor Small Cell	<300 mW per antenna	Operator managed	Lightly Coordinated with macro layer, LTE or 3G gateway
Distributed Radio System (DRS)	<300 mW per antenna	Operator managed	"Deeper" CRAN architecture where remote hub unit distribute IF signal to multiple radio units
Enterprise Small Cell	50 to 300 mW/antenna	Enterprise or Neutral Host purchased and managed	Autonomous node (Gateway) or local controller.
Residential Femtocell	<50 mW/antenna	Consumer or SOHO managed	Autonomous node (Gateway)

Source: Mobile Experts

Figure 23. Detailed Definitions for each equipment category

North America:	USA and Canada
Latin America:	Mexico through South America, including the Caribbean
Europe:	Western and Eastern Europe, including Russia
China:	China, including Tibet and Hong Kong
Asia Pacific:	India through Australia/Micronesia, excluding China
Middle East/Africa:	Pakistan and Turkey through Africa

Source: Mobile Experts

Figure 24. Detailed Definitions for regions

Multimode:	Capable of multiple simultaneous air interface standards (LTE, HSPA, GSM, etc.)
Adaptable:	Capable of one air interface standard at a time, but reprogrammable
Single-mode:	Capable of only one air interface standard

Source: Mobile Experts

Figure 25. Detailed Definitions for multimode/single mode

Multiband:	Capable of operating in multiple frequency bands, one at a time or simultaneously with separate baseband datastreams
Carrier Aggregation Units:	Units which operate in multiple bands with a single baseband datastream (inter-band CA)

Source: Mobile Experts

Figure 26. Detailed Definitions for multiband and carrier aggregation